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Alfalfa seed production in central Iowa as influenced by honey bees and certain other factors

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ALFALFA SEED PRODUCTION IN CENTRAL IOWA AS INFLUENCED BY HONEY BEES AND CERTAIN OTHER FACTORS

by

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INTRODUCTION

This thesis is a report of research on alfalfa seed production in central Iowa. The study was basically entomological, but several other lines of investigation were included in order to get a clearer and more complete understanding of factors that influence honey bees and seed production either directly or indirectly.

The main purpose of this research was to study honey bees as pollinators of alfalfa under field conditions, but because weather, agronomic, and other ecological factors may greatly influence the behavior of bees, it was deemed necessary to evaluate these influences.

Pilot studies of pollination and techniques to be used were made in the fall of 1949 and spring of 1950. Principal research was done during the summers of 1950 and 1951 in the vicinity of Ames, Iowa. Four fields used for the studies in 1950 were furnished by cooperating farmers and the Iowa State College Farm Service. In 1951 experiments were conducted on a single field planned and laid out by members of the Departments of Zoology and Entomology, Agronomy, and Agricultural Engineering. This field was located on the Agricultural Engineering Research Farm at Ames.

Production of alfalfa seed in Iowa has been an uncertain venture. Preliminary observations of pollination in this state, and experiences of others in various seed producing areas, had indicated that lack of pollination was probably a limiting factor in seed production.

Occasionally good alfalfa seed crops are produced in Iowa, but, as Figures 1 and 3 indicate, acreages and yields of alfalfa have been comparatively low through the years. Conversely, prices of alfalfa seed in Iowa have been relatively high compared to average prices of seed in other states (Figure 2).

The soil and climate in Iowa are ideal for profitable production of grain crops, particularly corn. Naturally the agriculture of the state is geared largely to the production of the crops well adapted to its soil and weather. Production of corn and other grains does not account entirely for the low acreage of alfalfa seed grown in Iowa. Thousands of acres of legumes other than alfalfa are grown in the state; red clover has been the favorite legume grown for seed for many years (Figure 4). Red clover is well adapted to the climate and rotation programs in Iowa and has usually been a relatively dependable crop for seed production in this area.

Sweetclover seed production, as shown in Figure 5, has been less important than red clover seed production in Iowa, but sweetclover is an important consideration in alfalfa seed production because it is more attractive to honey bees than alfalfa. Thus it may limit alfalfa seed production by attracting bees from the alfalfa in neighboring fields.

Although Iowa has not produced large amounts of alfalfa seed consistently, there was considerable interest in seed production in 1949. Several factors contributed to this interest:

1. Farmers were interested because alfalfa seed prices were high and supplies were limited. They wanted to produce seed for their own use and also for cash income. During the period shortly after World

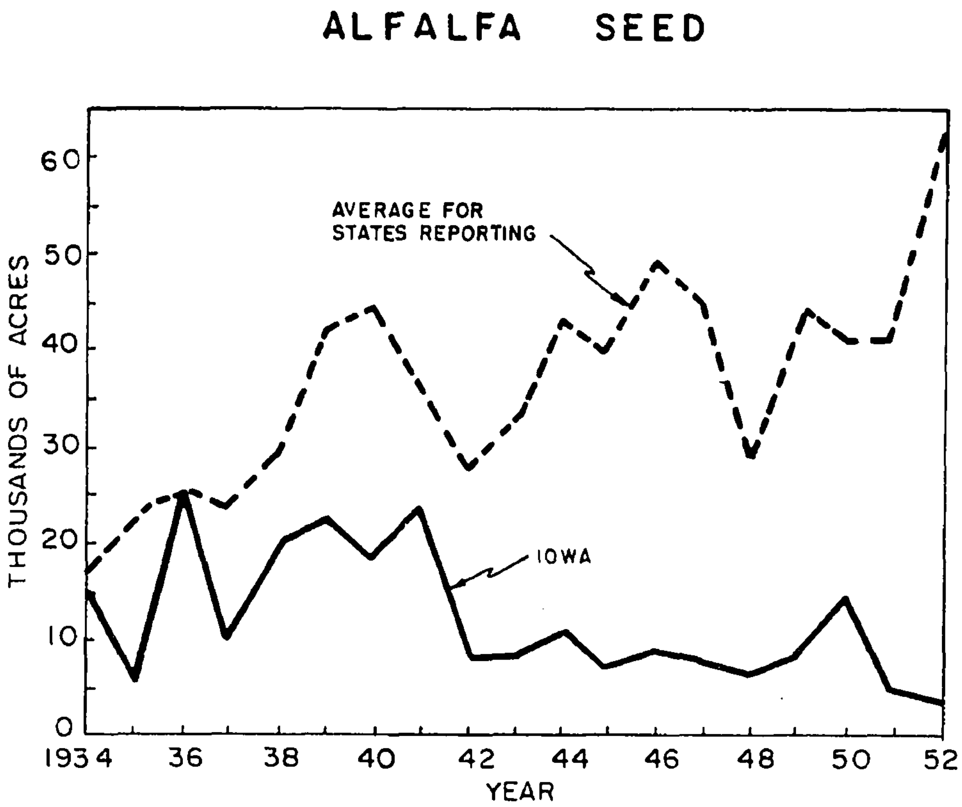


Fig. 1. Acreage of alfalfa seed grown in Iowa compared with average for other states reporting, 1934-52.

Source: Agricultural Statistician, 1936 through 1951.

Crop Reporting Board, Bur. Agr. Econ., U. S. Dept. Agr., Dec. 19, 1952.

Seed Crops, Agr. Mktg. Ser., U. S. Dept. Agr., Dec. 24, 1953.

Fig. 2. Average price of alfalfa seed grown in Iowa compared with average for other states reporting, 1934-52.

Source: Agricultural Statistician, 1936 through 1951.

Crop Reporting Board, Bur. Agr. Econ., U. S. Dept. Agr., Dec. 19, 1952.

Seed Crops, Agr. Mktg. Ser., U. S. Dept. Agr., Dec. 24, 1953.

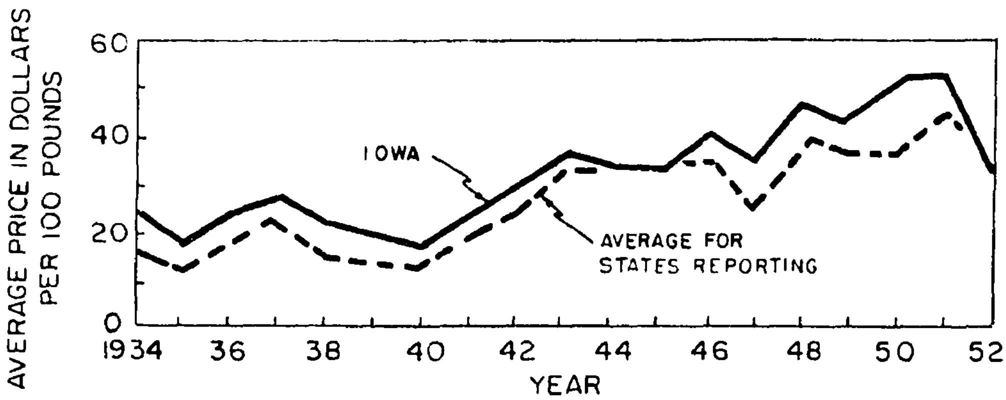
Fig. 3. Average yield of alfalfa seed grown in Iowa compared with average for other states reporting, 1934-52.

Source: Agricultural Statistician, 1936 through 1951.

Crop Reporting Board, Bur. Agr. Econ., U. S. Dept. Agr., Dec. 19, 1952.

Seed Crops, Agr. Mktg. Ser., U. S. Dept. Agr., Dec. 24, 1953.

ALFALFA SEED



ALFALFA SEED

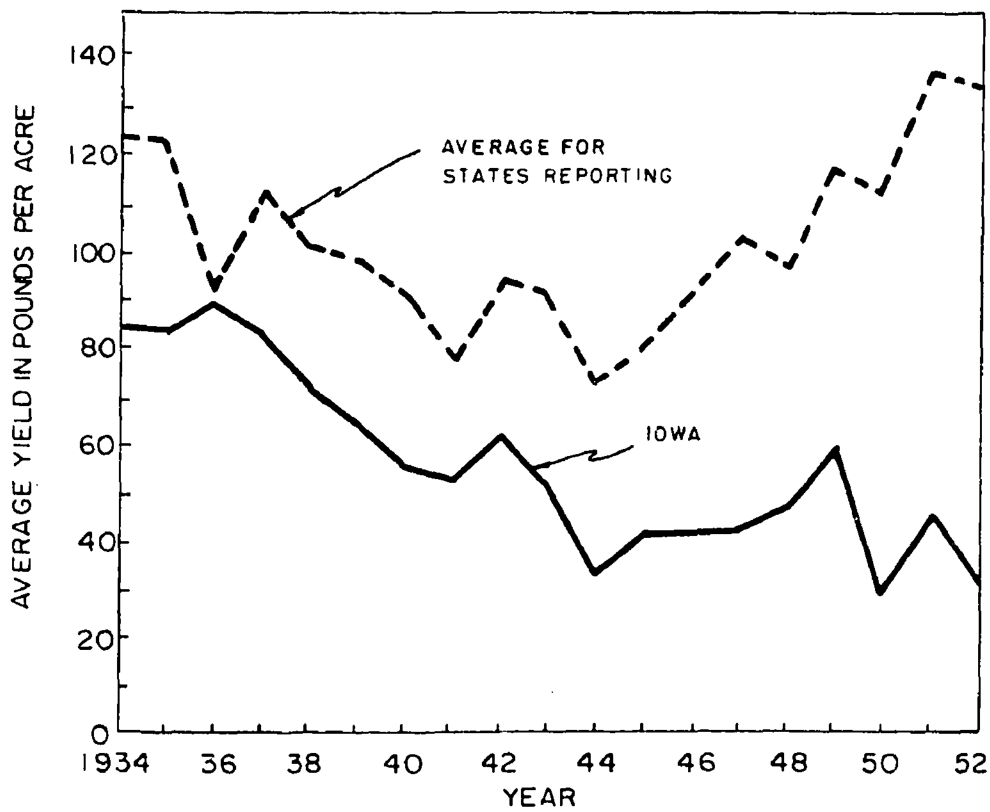


Fig. 4. Acreage of red clover seed grown in Iowa compared with average for other states reporting, 1934-53.

Source: Agricultural Statistician, 1936 through 1951.

Crop Reporting Board, Bur. Agr. Econ., U. S. Dept. Agr., Dec. 19, 1952.

Seed Crops, Agr. Mktg. Ser., U. S. Dept. Agr., Dec. 24, 1953.

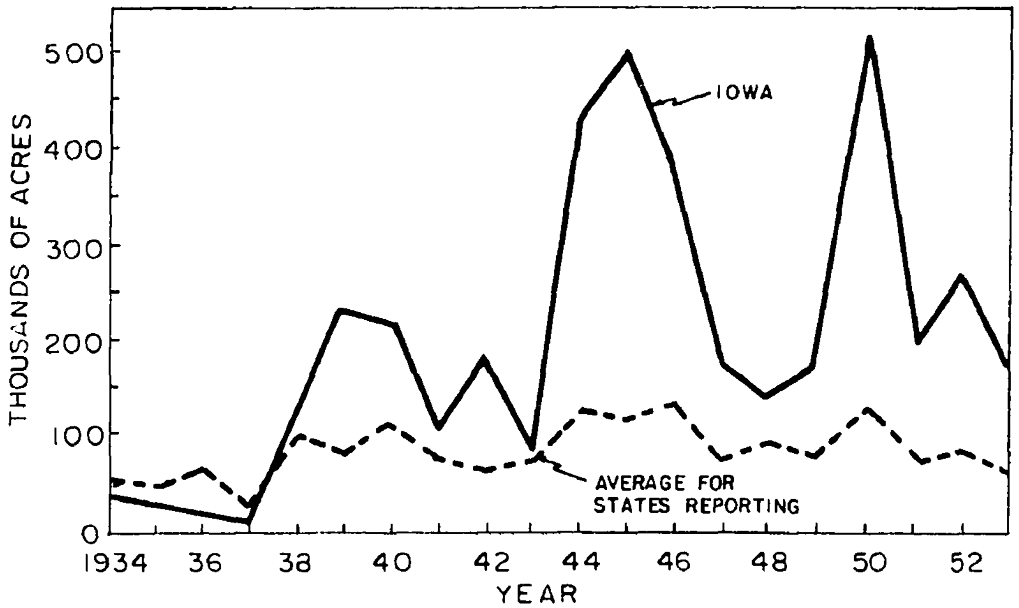
Fig. 5. Acreage of sweetclover seed grown in Iowa compared with average for other states reporting, 1934-53.

Source: Agricultural Statistician, 1936 through 1951.

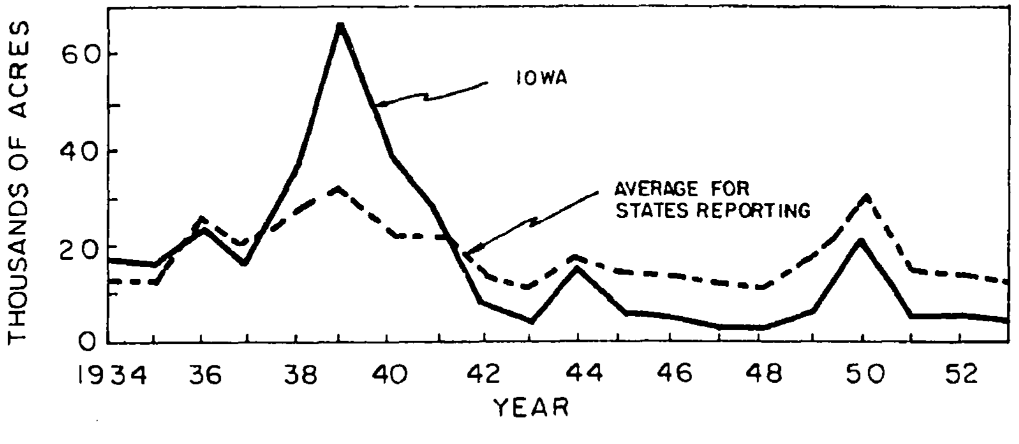
Crop Reporting Board, Bur. Agr. Econ., U. S. Dept. Agr., Dec. 19, 1952.

Seed Crops, Agr. Mktg. Ser., U. S. Dept. Agr., Dec. 24, 1953.

RED CLOVER SEED



SWEETCLOVER SEED



War II there was a need for changes from wartime crop output and for a return to good rotations and use of legumes for soil maintenance. There seemed to be a national awakening to the importance of encouraging grassland farming.

2. Iowa beekeepers were interested because they were being called on to assist in the pollination of legume crops. They had only limited information concerning the effectiveness and use of honey bees in pollination of alfalfa and needed more information before they could participate as partners in a sound seed production program. Reports of success in using honey bees to increase alfalfa seed yields in the West kindled interest in this possibility in the Midwest.

3. Iowa State College specialists were urging farmers to include more legumes in their farm programs. The college, as well as the farmers and beekeepers of the state, needed information to determine whether or not sound seed production programs could be developed.

While it was not to be expected that production of alfalfa seed in Iowa would develop into a farm enterprise as extensive as the culture of corn or other crops, the possibilities of a few farmers producing registered or foundation seed as a specialized crop or of farmers producing some of their own seed seemed worthy of investigation. Since Iowa lies in the zone of adaptation for some of the leading alfalfa varieties, it would be a service to farmers of the state and others requiring seed grown in adapted areas if Iowa could consistently produce some of this seed.

In view of the needs for more information concerning alfalfa seed production, the following study of honey bees and pollination of alfalfa was begun. The main objectives of the research were:

1. To study the general behavior of honey bees as pollinators of alfalfa under field conditions.

2. To determine the value of honey bees in increasing seed yields of alfalfa under Iowa conditions.

3. To investigate conditions that affect, directly or indirectly, the value of honey bees in pollinating alfalfa in Iowa.

4. To get information that would contribute to a better understanding of the alfalfa seed production problem as a whole.

REVIEW OF LITERATURE

Problems of alfalfa seed production have drawn the attention of scientists and others for more than 50 years. As a result there is so much literature available on this subject and subjects closely related to it that writing a complete review of this information would be a project in itself. The object of this review is to give a general history of alfalfa seed production problems and to point out some of the more important results of research on these problems. Several lines of investigation closely related to seed production are discussed briefly.

General History of Alfalfa Seed Production

The first attempt to grow alfalfa in the United States is believed to have been in Georgia in 1736, but substantial success was not achieved until 1850 when Chilean alfalfa was brought to California (Graumann and Hanson, 1954).

Difficulties in producing alfalfa seed were encountered early in the 1900's in several areas of the United States, and the great variability of seed yields in the Milk River Valley of Montana represented the common sequence of high to low seed yields found in other areas (Piper *et al.*, 1914). Utah, which once produced 42 percent of all the alfalfa seed in the United States (Sorenson, 1946), and Minnesota, which ranked first in the amount of alfalfa seed produced in 1936 (Burson *et al.*, 1954), are examples of states which found their yields drastically reduced for reasons that were not understood. In 1914 Piper *et al.* summarized the results of research begun in 1906 by United States Government agencies to assist in resolving alfalfa seed production problems.

An important contribution to the understanding of low yields of alfalfa seed was made by Sorenson (1932), who called attention to the injury of Lygus sp. to alfalfa. Later publications by Sorenson (1936, 1937, 1939, 1944, 1946), Sorenson and Carlson (1946), and others (Carlson, 1940, 1946b; Stitt, 1940, 1944, 1948, 1950; Jeppson and MacLeod, 1946; Bolton and Peck, 1946; Roberts, 1947; McMahon and Arnason, 1947; Smith and Linsley, 1947; Smith and Milchelbacher, 1948; Russell, 1949; Haws, 1949; Flemion, Poole, and Olson, 1949; and Anderson et al., 1952) showed that lygus bugs reduced seed yields of alfalfa and other plants. Most of the insect pests of alfalfa can now be controlled with insecticides.

Lack of pollination was pointed out by Piper et al. (1914) as a major cause of variations in alfalfa seed yields. Many publications since that time have contributed to the present understanding that honey bees and/or other insect pollinators are necessary for satisfactory yields of alfalfa seed; these include: Tysdal (1940), Vansell and Todd (1946), Grout (1949, ca. 1949), Utah Agricultural Experiment Station (1950), Vansell (1951), Bohart (1952), and Todd and Vansell (1952).

In some parts of the country the uncertainty of obtaining adequate pollination has been eliminated, and honey bees are used commercially as pollinators in producing profitable yields of alfalfa seed (Vansell, 1951).

The literature on seed production which has accumulated since 1914 contains many opinions and conclusions that appear contradictory. Not all controversies have been completely or harmoniously settled, but many of the major problems of pollination have been elucidated and solutions proposed. Variations in the effectiveness of honey bees in pollinating alfalfa are becoming better understood, but remedies for problems of seed production in some areas are yet to come (Wilsie, 1949b; Graber, 1953; and Burson et al., 1954).

General Publications on Alfalfa Seed Production

Piper et al. (1914), who summarized the results of several early studies made between 1906 and 1914, presented the following conclusions:

1. Unsatisfactory numbers of pollinating insects and detrimental effects of thrips and other destructive agencies were apparently two of the main factors associated with the great variation in alfalfa seed yields.

2. Flowers tripped artificially or by insects appeared to produce more seed pods than flowers that were not tripped.

3. A few seed pods formed even though the flowers were not tripped. Such occurrences were rare and only small amounts of seed formed in these pods.

4. Honey bees tripped few of the flowers they visited, 0.31 to 4.67 percent. Leaf-cutter bees tripped 90 percent or more, and bumble bees tripped approximately 30 percent of the flowers they visited.

5. Cross-pollination appeared to give greater yields of alfalfa seed than self-pollination, as was indicated by an average of 1.4 seeds

per pod from self-pollinated flowers, compared with 2.38 seeds per pod from cross-pollinated flowers.

6. Some alfalfa flowers were tripped automatically without the aid of insects. This kind of tripping appeared to be associated with warm, sunny days and possibly atmospheric or other weather conditions. It was concluded that automatic tripping alone might account for the great variation in seed production during different seasons in the same locality. (Later studies have indicated that it is improbable that automatic tripping alone results in satisfactory seed yields (Tysdal, 1946a; Vansell, 1951).)

7. Studies on the relationships of stigmatic cells to effective pollination of alfalfa indicated that the mechanical effect of the stigma striking the standard petal was not necessary to insure fertilization. (Hobbs (1952) interpreted the evidence available as conclusive and stated that stigmatic cells must be ruptured and fluid released for pollen germination and resultant fertilization of the eggs within the ovules of alfalfa flowers.)

8. There did not appear to be a definite relationship between the age of flowers when tripped and the percentage of pods that developed.

9. Although some insects are natural agents of cross-pollination, good crops of seed may be produced even though these insects are few. (This is not generally considered true at present (Vansell, 1951).)

10. Butterflies, moths, and other night-flying insects appeared to have little influence on alfalfa pollination.

11. Some studies indicated it might be practical to develop a

machine to trip alfalfa flowers and thus increase seed production.

Piper's report is valuable because it points out two problems that are still considered vital in successful seed production: (1) pollination and (2) control of injurious insects. Also it previewed several lines of study that have been pursued since 1914.

Information collected by the United States Department of Agriculture regarding alfalfa seed production was brought together by Graumann and Hanson (1954), and Vansell (1951) has published on the use of honey bees in alfalfa pollination. More than half a century of observation and study on alfalfa, including seed production, in Wisconsin has been summarized by Graber (1953). Three general bulletins on alfalfa have been published by Kansas, one of the leading states in alfalfa seed production (Franklin, 1951; Grandfield, 1951; and Grandfield and Franklin, 1952). Early studies of alfalfa seed production in Utah were made by Carlson (1935), and in 1950 the Utah Agricultural Experiment Station, which has been a center of alfalfa seed research for many years, published a compilation of its results. Some theses written on various aspects of alfalfa seed production are those by Roberts (1947), Phillips (1948), Haws (1949), Nickelson (1949), Noyes (1949), Elling (1950), Franklin (1950), Pedersen (1951), Hobbs (1952), and Nelson (1953).

Pollination

Tripping

The structure of the alfalfa flower has been described by Hayward (1948, p. 312). The floral structures bearing the pollen (anthers) and the female receptacle of the pollen (stigma) are enclosed between two petals known as the keel. In order for seed to develop it is necessary for the pollen from the flowers of one plant to be transported and deposited on the stigma of a flower on another plant. The release of the floral structures from the keel is known as tripping and has been described by various authors (Tysdal, 1946a; Utah Agricultural Experiment Station, 1950; Grandfield, 1951; Grandfield and Franklin, 1952; and Graber, 1953).

Pollination literature contains many controversial ideas regarding the question: Do alfalfa flowers need to be tripped in order to obtain a satisfactory seed yield? The answer to this question is becoming clearer as more is learned about genetic differences of alfalfa; _i.e._, a single answer does not seem to apply to all varieties (Carlson and Pedersen, 1946; Westover, 1946; White, 1946; Tysdal, 1947; Elling, 1950; Utah Agricultural Experiment Station, 1950; Grandfield, 1951; Jones, 1951; Pedersen, 1951; Wilsie, 1951; Graber, 1953; and Petersen, 1954).

One of the early investigators of alfalfa seed failures (Blinn, 1920, p. 25) wrote that "...there was no clear evidence that bees or other insects were essential to alfalfa seed production." Concerning experiments in which alfalfa was covered with cages, he stated, "The covered experiments showed that fertilization could take place without the insects and did so take place." Blinn (1920, p. 26) also wrote, "There was practically no difference in seed yield resulting from hand tripping of the flowers. While some plants seemed to have more 'tripped' flowers than others, it could not be said that the 'tripped' flowers were more inclined to set seed."

Brink and Cooper (1936) believed their evidence showed that they obtained effective pollination without tripping. They found in the greenhouse that tripping is essential to seed setting, but that in the field many pods may arise from untripped flowers. They concluded that the role of the stigmatic membrane is variable in alfalfa varieties and that much irregularity in seed set is associated with this membrane.

The general idea that tripping is not necessary is disputed by Piper _et al_. (1914), Tysdal (1940, 1946a), White (1946), Vansell (1951), and Grandfield (1951), whose investigations have indicated that seed set is limited if alfalfa flowers are not tripped. Most agronomists now maintain that the alfalfa flower has to be both tripped and cross-pollinated if an appreciable amount of seed is to result and that insects are the principal agents for both (Vansell, 1951).

Differences in the genetic character of alfalfa varieties and those associated with various influences of the environment need to be considered in discussions of tripping and seed production. Studies by plant breeders have indicated that there are differences in the tripping velocities of certain genotypes of alfalfa (Carlson and Pedersen, 1946). White (1946) has discussed differences in nonself-tripping alfalfa and self-tripping alfalfa. Armstrong (1946) indicated that certain types of alfalfa may trip automatically.

Akerberg (1952) reported that there was variation in the amount of automatic tripping between different strains of alfalfa and found 60 percent automatic tripping on favorable days. He believed that automatic tripping was important in seed production in Sweden under certain conditions. Jones (1952a) stated that certain plants tripped easily and produced good yields of seed, but he felt that much of the seed was produced by cross-pollination resulting from bee visitations.

Tysdal (1940) found a correlation between temperature and the amount of tripping. He recorded a gradual increase in the number of flowers tripped per hundred per hour in the range from 70° F. to 100° F. Franklin's work for 1946 through 1949 (1950) did not show a consistent association in the percentage of flowers tripped and the time of day, temperature, or relative humidity. Tysdal (1946a) concluded that rain, sun, and self-tripping are responsible for a limited amount of tripping. Vansell (1946) reported that 59 percent of the blossoms observed in a dry field in Utah were tripped, compared with only 12 percent in a wet field. Dwyer and Allman (1932) in a laboratory study found that with varying conditions of relative humidity alfalfa flowers tripped readily at temperatures ranging from 100° F. to 108° F. He stated that these temperatures are frequently exceeded in direct sunlight during the summer months.

Cross-pollination and selfing

Even if alfalfa flowers trip automatically there is evidence that foreign pollen needs to be deposited on the stigma if satisfactory seed yields are to result in alfalfa varieties that are highly cross-fertile. Brink and Cooper (1936) showed that 66 percent of the ovules were fertilized in young pods after cross-pollination, but that less than 15 percent were fertilized after self-pollination.

Tysdal (1940) found that cross-pollinated flowers produced about three times as much seed as those that were selfed. Akerberg (1952) observed high percentages of automatic tripping, but he also presented evidence that cross-pollination was important. He found that 1 percent automatic tripping resulted in about one-fourth the amount of seed produced by 1 percent cross-pollination. Elling (1950) found big differences in the amounts of seed set on different clones when they were selfed or cross-pollinated.

Because of the structure of the alfalfa flower its pollen is not usually considered to be wind disseminated. Dwyer and Allman (1932) claimed that pollen was frequently found on standards of untripped flowers, but Petersen (1954) stated that few grains were found on standard petals where the stigma contacts the petal if the flower is tripped automatically.

Pollinators

Honey bees and wild bees are the principal pollinators of alfalfa (Utah Agricultural Experiment Station, 1950; Burson _et al._, 1954), although soldier beetles and a few other insects are known to pollinate varying amounts (Drake, 1946; Thompson, 1948; and Utah Agricultural Experiment Station, 1950).

Honey bees as pollinators of alfalfa. The value of honey bees as pollinators of alfalfa has been studied extensively in the United States and other areas. Results of these investigations indicate that there are variations in the behavior of honey bees in different areas (Utah Agricultural Experiment Station, 1950; Knowlton, 1952; Vansell, 1952). It is evident that some of the conclusions expressed regarding the value of honey bees in pollination of alfalfa do not apply equally in all areas.

It seemed unlikely to Wilsie (1949a) that honey bees could be very effective in increasing alfalfa seed yields in Iowa or in the Corn Belt where there is an abundance of pollen from corn and clovers when second crop alfalfa is in bloom. Graber (1953) wrote that honey bees were not very efficient pollinators of alfalfa except in hot, dry climates where alfalfa blossoms trip easily. Observations in Minnesota indicated that honey bees tripped only 0.32 percent of the alfalfa flowers they visited (Burson et al., 1954), and those observed in Washington tripped less than 1 percent (Menke, 1952). Hobbs (1952) concluded that honey bees did not set enough seed to warrant a recommendation for using them as alfalfa pollinators under the conditions of his study in Canada.

In Utah the value of honey bees as alfalfa pollinators varied greatly from one area to another according to Knowlton (1952), who reported that pollen-collecting bees rarely exceeded 1 percent of the active bees in alfalfa fields of the Cache Valley, but 12 to 30 percent of the bees observed in Washington County were pollen-collectors. Pedersen and Bohart (1953) found that in Utah nearly all the honey bees observed had pollen at the base of their mouthparts. They felt this indicated that most of these honey bees had tripped some alfalfa flowers.

Studies have shown that in some parts of Utah honey bees can be used to pollinate alfalfa grown for seed (Utah Agricultural Experiment Station, 1950). An investigation by Vansell and Jones near Davis, California, demonstrated that honey bees could be used in producing yields of alfalfa seed that exceeded 1,000 pounds per acre (Dadant, 1951). Since 1949 the acreage of alfalfa seed in California has increased tremendously, and honey bees are used to insure pollination (Whitcombe, 1952; Graumann and Hanson, 1954).

A number of factors influencing the effectiveness of honey bees as pollinators of alfalfa, either directly or indirectly, have been investigated. There is some evidence that the pollinating ability of various strains of honey bees may vary sufficiently to merit study of these differences (Rymashevskaia, 1952; Rothenbuhler, Gowan, and Park, 1953). Rymashevskaia (1952) observed that Caucasian bees and what he calls "local" bees visited more nontripped flowers than tripped ones. He noted that Caucasian bees tripped 58 percent of the flowers visited, while local bees tripped only 15 percent.

Bees rarely perform any useful work at temperatures below 50° F., and when temperatures approach 100° F., bees seldom go to the field but remain idle within the hive or cluster on the outside of the hive, according to Park (1949). Park's report indicated that single, inactive bees soon lose the ability to fly at 50° F. and that at temperatures below 45° F. they lose all power of motion. He pointed out, however, that in abnormal conditions bees will go out on cleansing flights or bring badly needed supplies of food or water at temperatures somewhat below 45° F.

A review and discussion of the literature on the influence of light on honey bee activities are given by Butler and Finney (1942). Bees do not fly out in great numbers when it is cloudy, according to Vansell

(1942). Butler, Jeffree, and Kalmus (1943) also reported that heavy clouds passing over the sun caused large numbers of bees to return to the hive and reduced the distance foraging bees flew from the hive. Von Frisch (1950, 1952) stated that bees can perceive the plane of vibration of polarized light and use it in their orientation. He explained that when a cloud cover opens and patches of blue sky appear, bees can orient themselves by the position of the sun, even though they cannot see it. Light coming from the clouds is not polarized, but light from blue sky is partially polarized.

Butler's observations (1945) led him to believe that the direction of prevailing winds, especially in windy districts, exerts considerable influence on the direction honey bees fly and, therefore, on the fields they visit. Usually bees will not forage long if wind velocity exceeds 15 miles per hour (Park, 1928). Vansell (1942) found that wind reduced the activity of field bees. Franklin (1950) reported that neither wind nor clouds interfered seriously with the activities of pollinating insects during his studies, but relative humidity and temperature affected bee activity at times.

Differences in length of season may account for some of the variable results obtained in the use of honey bees for pollination, according to Hobbs (1952). He concluded that bees had a 10-day shorter pollinating period in Alberta than in Utah and that this reduced time for pollination limits the usefulness of honey bees as pollinators in southern Canada. Other reasons given by Hobbs for the ineffectiveness of bees were:

1. Plant competition. Sweetclover, prairie clover, mustard, and evening primrose seemed to be preferred by honey bees over alfalfa as sources of pollen. Nectar of other plants was also more attractive than nectar from alfalfa.

2. Low percentage of tripping by honey bees and too few bees present in the field to compensate for this low efficiency.

3. High incidence of self-pollination resulting from flowers tripped by bees not forced to gather pollen, as indicated by a lower number of seeds per pod in open-pollinated areas compared to seeds in pods formed in areas where bees were caged on alfalfa.

Wilsie (1949b) cited unfavorable weather as a factor which limits the value of honey bees as pollinators in Iowa. He explained that the amount of time bees can work in the fields is often limited by rain or dull weather at critical times when alfalfa is in bloom.

Wery (1904) stated that nectar does not attract bees and suggested that the attraction exercised by form and color is approximately four times as strong as that of perfume, pollen, and nectar together. This opinion is contrary to that of a number of other workers. Nectar abundance and nectar concentration seem to have considerable effect on honey bee activity, according to Vansell (1934), Butler (1945), von Frisch (1950), Pedersen (1951), Grandfield (1951), Shuel and Pedersen (1952), and Beutler (1953). Butler (1941) said bees will work the plant species in which the nectar is most abundant and most easily obtainable, provided concentrations are about the same in all species. Wykes (1952) studied the influence of nectar sugars on bees and found that the descending order of preference was sucrose, glucose, maltose, and fructose. Mixtures of sugars were more attractive than any single sugar, and changing concentration did not seem to change relative preferences. Wykes performed experiments in the field and in the laboratory and decided that the laboratory studies gave a sound index of relative attractiveness of different sugar solutions to bees.

Shuel and Pedersen (1952) observed that the difficulty of using bees for pollination increases as one moves east and north from the driest regions of the United States. They suggested that the more humid areas have an abundance of other nectar plants that distract bees from alfalfa.

Grandfield (1951) cited work by Wilsie which showed that a clone with dark purple flowers was worked more by bees than other clones, but it set a small amount of seed. Grandfield's results indicated that light-colored flowers contained more nectar than dark flowers under cage conditions but less outside.

Evidence by Ribbands (1950) showed that chloroform had no after-effects on pollen gathering or longevity or memory of bees. Carbon dioxide induced permanent changes in foraging behavior of bees; those observed changed from pollen collection to nectar collection. Treating bees with carbon dioxide or nitrogen induced earlier foraging but seemed to eliminate wax secretion and brood rearing.

Vansell and Roberts (1946) found that variations in bee populations on plots receiving different insecticide treatments seemed to be directly related to differences in flowering -- the more flowers produced, the more bees present per unit area. Roberts (1947) studied the effect of *Lygus* infestation on flowering and pollination of alfalfa, and found no correlation in *Lygus* populations and amount of tripping. His results showed that flowering and pollination may occur irrespective of *Lygus* infestations if *Lygus* populations average 2.98 per sweep or less. Roberts also reported that there was an average of 3.39 bees per yard on a total of more than 1,300 square yards before dusting an area with insecticide and an average of 2.83 afterward. Application of DDT to alfalfa fields in bloom has been reported to reduce bee populations and should be avoided (Todd, 1946). Todd also gave evidence showing that under certain conditions bees are repelled for 2 or 3 days after fields have been dusted with DDT.

Foraging behavior of honey bees. Foraging behavior of bees on alfalfa was investigated by Reinhardt (1952). His objectives were to test a theory that bees learn, and to determine how pollination of alfalfa might be improved through an understanding of their behavior. He developed a system of recording each action of the bees as they visited alfalfa flowers.

Three classifications of honey bee foragers were described by Reinhardt: (1) nectar-gatherers, (2) nectar-trippers, and (3) pollen-gatherers. Nectar-gatherers are characterized as bees which commonly approach alfalfa flowers from a side position and remove nectar without tripping the flowers they visit except on rare occasions. Reinhardt concluded that nectar-gatherers were bees that had learned through foraging experiences to remove the nectar without tripping the flowers. Nectar-trippers were described as nectar-gathering bees that inserted their tongues directly into the corolla and frequently tripped flowers. The behavior of these bees indicated an unstable and indefinite pattern of approach. About one-third of these bees observed eventually changed to a side approach, which resulted in decreased tripping, habitual use of the new approach, and an increased rate of visitation. Bees that failed to shift their pattern to the side approach had a nervous behavior, retained a variable working pattern, worked slowly, and occasionally developed fixed patterns of visiting withered or tripped flowers. Pollen-gathering bees were rarely observed under usual conditions, but those observed tripped a large percentage of the flowers they visited. Two that were observed tripped a larger percentage of flowers visited a second day than a first. Pollen-gathering bees varied in their ability to extricate their tongues from tripped flowers, but, in general, they did it easier than nectar-trippers. Pollen-gatherers worked at a rate of 2 to 10 flowers per minute. More than half of those observed worked within the limits of five to seven flowers per minute.

In Reinhardt's study pollen-gathering bees required 79 to 140 visits to flowers to gather a load of pollen and tripped an average of 66.5 percent of the flowers visited. The rate of tripping ranged from 1.8 to 12.0 flowers per minute; the average rate was 5.6. Pollen-gathering bees exhibited a nervous behavior similar to that of nectar-trippers, and they used an approach to the flower similar to that used by nectar-trippers. Side-workers visited an average of 6 to 23 flowers per minute, and half of these fell in the range of 12 to 17. Nectar-trippers did not increase their speed of visits, but the increased speed of side-workers was very evident.

To check the theory that tripping could be increased by providing new and promising sources of nectar in alfalfa, Reinhardt excluded bees from certain areas for a period of time by using cages. Later the cages were removed and these areas exposed to bees. In 12 of 14 trials the tripping was significantly higher on plots that had been caged than on adjacent exposed areas. The amount of tripping appeared to diminish after initial exposure.

Reinhardt concluded that flower condition did not influence the working position of bees on flowers because side-workers and nectar-trippers were frequently seen together. Also the behavior of the nectar-trippers demonstrated that they did not know how to avoid the "traps" of alfalfa flowers. Slowness of nectar-trippers was not due to large volumes of nectar or time consumed in struggling to get released from tripped flowers, because slow and fast bees were observed at the same time and under the same conditions. The speed of 65 non-trippers on flowers having a high volume of nectar differed only a little from that of 60 others of similar skill visiting plants having a low volume of nectar. Bees acquired skill in visiting flowers by practice. This was indicated by their rapid selection of fresh untripped flowers, perfect positioning in the same stance on each flower, quick insertion of the tongue without tripping, precision in all movements, and a change in speed of work.

Inexperienced bees would be expected to forage close to the hive, and if inexperienced bees trip more flowers than experienced bees, the seed set near the hives might be expected to be greater than at a distance away. Heavier seed set was observed within about 40 or 50 yards of an apiary in some of Reinhardt's investigations. A study of honey bee behavior by Butler, Jeffree, and Kalmus (1943) revealed that bee populations increased the nearer bees were observed to the hive.

Synge (1947) studied the quantity and kinds of pollens gathered by honey bees. About 100 plants were found to be sources of pollen and about 54 percent of the pollen collected was from legumes. Foraging behavior of honey bees gathering pollen and gathering nectar was described by Franklin (1950). Franklin observed that pollen-gathering bees visited flowers in the same manner as nectar-gathering bees when the latter tripped flowers to get pollen. He also reported that pollen-gathering bees had a lower pitched hum than the nectar-gathering bees, visited lower racemes more than nectar-gatherers, and collected nectar through the side of the flower. Pollen-gathering honey bees tripped an average of 45 percent of the flowers visited, but nectar-gathering honey bees tripped an average of only 2.5 percent.

Observations reported by Petersen (1954) indicated that honey bees visited lucerne mostly for nectar under conditions in Denmark. Bees he observed seldom tripped alfalfa, but some that did were trapped and had difficulty releasing themselves. Petersen suggested that accidental trippings probably resulted in self-pollination. He found that 97 percent of the visits to alfalfa were oblique (not through the throat of the flower) and that about 0.5 percent of these flowers were tripped. Approximately one-fourth of the visits were over the standard petal, and about 75 percent of these visits resulted in tripped flowers.

Studies of the foraging behavior of bees by Ribbands (1949) indicated that foraging by honey bees was a continuous exercise of choice and a comparison of past and present memories. Ribbands, who preferred the term "attached" to the term "fixed" used by von Frisch, believed that foraging honey bees often change crops to adjust to the inconstant conditions of weather and crops about them. Bee constancy to plant species while foraging is reviewed by Ribbands (1953a).

Singh (1950) investigated the localization and duration of bee visits to small areas. His studies were confined largely to crops and plants other than alfalfa, but he concluded that individual bees tended to work on relatively small areas for varying lengths of time, depending on crop, weather, and plant conditions.

Honey bees returned to colors associated with food encountered at the time food was approached and not with colors placed under the food at the time of feeding or leaving, according to Allee _et al._ (1949). Color vision in bees was studied by Hertz (1939) and Butler (1951). Ribbands (1953b) presented evidence to show that bees did not communicate color to each other, but Lubbock's work, cited by Butler (1949), indicated that bees distinguished between certain colors.

Managing and training bees for pollination. Remarks by Bohart (1948) in answer to questions regarding what might be done to increase tripping by nectar-collecting honey bees indicated that definite answers were not available at that time, but he outlined these general principles for guidance:

1. Alfalfa flowers protected from bees and later exposed to them seem more attractive, and the amount of tripping is higher than before the protected period. (This view has since been substantiated by Pedersen (1951) and Reinhardt (1952).)

2. Tripping is sometimes greatest near the hives. (This observation agrees with that of Vansell (Dadant, 1951) and Reinhardt (1952).)

3. Some varieties of alfalfa attract more nectar-collectors than others, but easy-tripping varieties do not seem to get increased pollination.

4. Tripping is often greatest at the beginning and toward the end of the flowering season.

Other suggestions given in a discussion following Bohart's remarks were:

1. Eliminate competing pollen sources. This would have to be complete and far reaching.

2. Bring alfalfa into bloom in periods of competitor scarcity.

3. Improve the attractiveness of alfalfa to bees.

Drake (1948) stated that seed yields in Iowa and Nebraska were improved by staggering cuttings of alfalfa and reducing the size of areas left to be pollinated in order to concentrate the available bees on smaller areas. Vansell (1951) suggested moving colonies into alfalfa seed fields at intervals to improve pollination. He pointed out the disadvantages of this system to honey production, but expressed the opinion that until more was known about stimulating pollen collecting in alfalfa, the most feasible way to increase seed production was to increase the number of bees in seed fields.

Moving bees into alfalfa fields only when good bloom is present, then moving them out, and bringing in new colonies at 7- to 10-day intervals was recommended as a means of increasing the effectiveness of honey bees as pollinators by Todd and Vansell (1952). They suggested that a practical limit for bee populations was five to six bees per square yard and advised that the number of colonies to use depended on the kind and quality of flowering plants within range of the alfalfa field and on bee activity. Their general recommendations were: one colony per acre when alfalfa is in one-fourth bloom, three colonies per acre if there is extensive alfalfa pollen collection, and six or more per acre if pollination is mostly dependent on nectar-trippers. Scattering the hives in groups of 10 to 12 colonies throughout the field was also suggested. Jones (1952b) found that planting complementary crops, such as trefoil and cotton, in close proximity resulted in improved alfalfa seed set.

Experiments conducted by Soboleva (1952) indicated that honey bee populations and alfalfa seed yields were increased where the bees were trained by feeding them sugar solutions and extract of alfalfa flowers. Daily weight gains at the "trained hives" were also greater than those of the control hives. Tsygankov (1954) claimed that feeding honey bees aromatic syrup (contents of the syrup not stated in abstract) increased the radius the bees worked and resulted in nearly 100 percent increase in seed yield.

<u>Wild bees</u>. Wild bees and their value as pollinators of alfalfa have

been studied by many investigators; among these are Sladen (1918), Peck and Bolton (1946), Akerberg and Lesins (1949), Franklin (1950), Utah Agricultural Experiment Station (1950), Bohart, Knowlton, and Bailey (1950), Bohart (1952), Bohart and Knowlton (1952), Hobbs (1952), Larkin (1952), Todd and Vansell (1952), and Burson *et al*. (1954). Certain wild bees are plentiful enough to set good seed crops in some areas (Todd and Vansell, 1952; Menke, 1952). However, their dependability for adequate pollination is limited by yearly fluctuations in their numbers and by the inability of man to increase their numbers sufficiently to meet his needs and to move them where and when they are needed (Utah Agricultural Experiment Station, 1950; Todd and Vansell, 1952; and Burson *et al*., 1954).

Surveys of alfalfa fields in four areas of California in 1945 indicated that alkali bees, leaf-cutter bees, and long-horned bees appeared to be the most important wild bee pollinators of alfalfa there. Bumble bees were relatively scarce and were regarded as unimportant in alfalfa pollination at that time (Linsley, 1946). Leaf-cutter bees and bumble bees were the most important pollinators for tripping alfalfa in northern Saskatchewan (Peck and Bolton, 1946) and in Iowa (Drake, 1948). Leaf-cutter bees, bumble bees, alkali bees, carpenter bees, Osmia bees, and long-horned bees are listed as some of the more important wild bees that pollinate alfalfa in some areas of western United States (Utah Agricultural Experiment Station, 1950).

Franklin (1950) concluded that the main groups of pollinators in Kansas were leaf-cutter and bumble bees. He indicated, on the basis of many thousands of observations, that the average efficiency by all species of bumble bees combined was 33 percent and for all species of leaf-cutter bees was 98 percent. A long list of wild bees in southern Alberta, Canada, is given and discussed by Hobbs (1952). Burson *et al.* (1954) found that bumble bees and leaf-cutter bees were the most important wild bee pollinators observed in Minnesota in 1951 through 1953. They reported that bumble bees tripped 34 percent of the alfalfa flowers visited, compared to 97.5 percent tripped by leaf-cutter bees. Two years of study in Washington indicated that female alkali bees tripped more than 95 percent of all the alfalfa flowers they visited (Menke, 1952).

Grant (1950) studied the flower visiting behavior of honey bees and wild bees. He observed that wild bees seem to have an instinct of flower constancy similar, in general, to that of honey bees. The behavior of some species of *Bombus* was relatively inconstant, whereas honey bees strayed occasionally.

Mechanical pollinators. Attempts to pollinate alfalfa by using mechanical devices have been reported in the literature (Schwanz, 1954). While varying claims of success and failure have resulted from these attempts, a device adaptable to general use has not yet been developed. Several difficulties are encountered in attempts to pollinate alfalfa with machinery. The flowers must be tripped and cross-pollinated over a period of time. Alfalfa flowers develop over a period of several weeks (Todd and Vansell, 1952), and it is difficult with a mechanical device to trip more than a relatively small proportion of the blossoms at any one time. Effecting cross-pollination with a machine is also a problem.

Other Factors Affecting Seed Production

The following section will consider seed production factors other than pollination, particularly those which have not been previously reviewed or only partially so. The interrelationship of factors affecting seed production is so complex that it is difficult to review them without overlapping. An outline which separates out and shows the relationship of many factors involved in alfalfa seed production has been prepared by Tysdal (1946b).

Injurious insects

A vast amount of literature is available concerning injurious insects and alfalfa seed production. Studies of lygus bugs and their importance in alfalfa seed production have already been cited. Other injurious insects that affect alfalfa seed production have been studied by various investigators. In addition to lygus bugs, Sorenson (1944) listed other mirid bugs, grasshoppers, alfalfa weevil, pentatomids, and some leafhoppers and thrips as seed pests in Utah. Some of the major alfalfa pests reported by Drake (1946) in Iowa were potato leafhoppers, alfalfa plant bugs, rapid plant bugs, lygus bugs, seed chalcids, and the following intermittent pests: grasshoppers, webworms, cutworms, armyworms, and pea aphids. The pests of alfalfa and alfalfa seed in Queensland were discussed by Jarvis and Smith (1946), and spittle bugs were listed as pests of alfalfa seed in Wisconsin (Scholl and Medler, 1947). Leafhoppers affected seed yields in Minnesota, but alfalfa plant bugs and tarnished plant bugs appeared to be more important than leafhoppers (Holdaway, 1952). Chalcid flies have been considered serious pests of alfalfa seed in some places (Sorenson, 1930, 1934; Drake, 1946; Jones, 1952b).

Many states where alfalfa seed is grown have publications giving recommendations for chemical control of injurious pests of alfalfa (Bayles, 1932; Smith and Linsley, 1947; Utah Agricultural Experiment Station, 1950; Gausman, 1950; Brannon _et al._, 1951; Peterson and Holdaway, 1951, 1952; Grandfield and Franklin, 1952; and Iowa State College, 1953). Graumann and Hanson (1954) have given the same kind of information on a nationwide basis for the United States Department of Agriculture.

Climatological factors

Whornham (1936) concluded from his studies of seed production in Millard County, Utah, that climate and weather did not appear to be major factors in controlling seed production. This may have been true for that particular area, but the conclusions of many other investigators indicate that weather often limits seed production (Wilsie, 1949b; Hobbs, 1952; Todd and Vansell, 1952; and Graber, 1953).

Carlson (1935, p. 45) intimated that an increased frequency of cloudy days and summer showers was associated with better seed yields in Utah. He has written, "The frequency of cloudy days and summer showers in seed districts is from 14 to 30 percent greater than for the regions of greater annual precipitation in Utah and in other sections where alfalfa-seed growing is of minor importance." Sunshine and below normal rainfall are two conditions usually associated with good seed yields, according to Grandfield (1951). Graber (1950) stated that alfalfa is not a good seed setter unless the environmental complex is precisely correct for seed formation. The ideal conditions he listed included (1) sunny days, (2) cool nights, and (3) steady water supply, not too much or too little.

Law (1952) suggested that low humidity during the growing season favors seed production. The average relative humidity for the southern part of the United States is 10 to 15 percent higher than that of the main alfalfa areas in the West, and the average annual minimum temperature is 37 degrees higher in the South than in western United States (Carr, 1948).

Agronomic factors

Plant. Thin alfalfa stands have been reported to produce more seed than thick stands (Blinn, 1920; Carlson, 1952).

Competition between alfalfa and plants that are more attractive to pollinating insects was a major factor in limiting seed production in some areas. The principal competitors of alfalfa for pollinators observed by Franklin (1950) in Kansas were white sweetclover, corn, and sorghum. Wilsie and Johnson (1946) wrote that honey bees seemed to prefer pollen from corn and many other plants to pollen from alfalfa. They concluded that it was unlikely that alfalfa seed would be increased materially in the Corn Belt by the presence of more honey bees. Lucerne attracts as many bees as red clover, according to studies made by Hammer (1949). A comparison of competing crops and plants in southern Canada was given by Hobbs (1952), who indicated that sweetclover was a preferred source of pollen for bees.

Bohart (1948) concluded that competition was not the only factor involved in differences in the amount of pollen collected by honey bees in some areas of Utah and that rarity of pollen collection from alfalfa by honey bees was not necessarily associated with competition from flowers more attractive than alfalfa as pollen sources. He suggested that alfalfa pollen itself may be more attractive in some areas than in others or that the attractiveness of some competing plants is about on a par with alfalfa.

Burson *et al*. (1954) reported that three diseases observed in northern Minnesota probably decreased production of alfalfa seed in that area. These were black stem, *Asochyta imperfecta*; *Stemphylium* leaf spot, *Stemphylium botryosum*; and common leaf spot, *Pseudopeziza medicaginis*.

High seed production in alfalfa is a genetically determined character, according to Jones (1951). He reported that good seed setters came into bloom 1 month after cutting, which was about a week earlier than the poorer yielding plants. The ability of alfalfa plants to resist or recover from injury by sucking insects also seemed associated with genetic characters. Jones stated that plant breeding studies might point the way to the development of alfalfa strains better adapted for seed production in certain areas.

Differences in tripping velocity were found by Carlson and Pedersen (1946) in different genotypes of alfalfa and tripping velocity was also shown to be associated with insect pollinator preference and low plant fertility. The alfalfa strain Du Puits seemed to have a greater tendency to self-tripping than other strains and appeared to be a good seed producer under Danish conditions, according to Petersen (1954). He pointed out that self-tripping may increase the effectiveness of honey bee visits.

Studies by Pedersen (1951) indicated an inherent difference in the attractiveness of alfalfa plants to bees. Also there was a highly significant difference in the volume of nectar obtained from the different clones of alfalfa he studied. Pedersen's data suggested that seed production might be improved by breeding. This was shown by higher seed yields and greater attractiveness to honey bees of certain plants he tested compared to others.

Big differences were found in the seed set on different clones by Elling (1950) when he selfed or cross-pollinated them. The percentage of flowers which were tripped and set pods ranged from 8 percent to 85 percent, and the number of seeds per pod averaged from one to three. He preferred to use the number of seeds per flower tripped, rather than the percentage of tripped flowers that set pods, as a method of evaluation. In general, the clones that set the highest number of seeds per flower when selfed also set the highest number of seeds per flower when crossed. Elling found that four clones which had low percentages of normal pollen produced progeny with low seed yields. He concluded that although clones with a high percentage of normal pollen did not always give acceptable seed yielding progenies, clones which had low percentages of normal pollen produced progenies that were low in seed production and should, therefore, be eliminated from breeding programs.

White (1946) reported that nonself-tripping alfalfa showed about 90 percent cross-pollination and that highly self-tripping plants which were also self-fertile were highly self-fertilized under conditions of open-pollination.

Soil. Ideal soil conditions for alfalfa seed include deep soil (Graber, 1953) and soil that is neutral and well drained (Sprague and Parsons, 1948). Alfalfa produces the best bloom when grown on deep loam soils with high fertility, good drainage, and a neutral reaction (Carr, 1946). Studies in Kansas by Grandfield (1945) gave evidence that organic reserves and soil moisture affect seed production, and Blinn (1920) reported that excess quantities of nitrates in the soil are associated with poor seed yields in many irrigated regions. There is general agreement that conditions which promote excessive vegetative growth are unfavorable to seed production, according to Brink and Cooper (1936). Whornham (1936) found a significant relationship between the physical properties of soil and alfalfa seed yield.

Nickelson (1949) reported significant differences in seed yields where different fertilizers were applied to alfalfa plots, and substantial increases in seed yields were obtained in Minnesota by the use of fertilizers (Burson *et al.*, 1954).

Nectar

An extensive review of the literature pertaining to nectar and many lines of study associated with nectar has been compiled by Beutler (1953). Topics discussed include composition of nectar; nectar secretion; and the effects of temperature, light, age of flower, soil, and soil moisture on nectar.

Park was one of the first to use a refractometer for evaluating nectar samples (Beutler, 1953). Chromatographic paper has been used for nectar analysis by Wykes (1952) and Bailey, Fieger, and Gertel (1954).

A long-term study of nectar flow as related to weather conditions in Kansas has been summarized by Moffet and Parker (1953). The effect of climatic conditions on nectar has been described by Kenoyer (1916). According to Shuel and Pedersen (1952) some species of Leguminosae tend to have threshold temperatures for nectar secretion of about 60° F., and wide temperature variations do not produce significant differences in nectar production. They reported that nectar yields at 45° F. were approximately 80 percent of those at 75° F. Shuel (1951) observed that low temperatures curtailed nectar secretion and found highly significant positive correlations between weight of nectar sugar and quantity of solar radiation. He suggested that waterlogging limited nectar secretion by hindering photosynthesis and that extreme dryness depresses the uptake of minerals which resulted in less sugar in nectar. Fahn (1949) wrote that relative humidity was related to nectar concentration, that nectar increased with increases in temperature, and that soil moisture increased the quantity and quality of nectar for 1 to 2 days after irrigation.

Shuel and Pedersen (1952) disclosed that secretion of nectar was dependent on the presence of surplus sugar in excess of that used in growth, respiration, and other physiological processes. Pedersen (1951) has observed that low bee populations and poor seed yields, which might be indicative of low nectar production, have been noticed in alfalfa seed fields with extreme vegetative growth. Wykes (1953) found that the sugar content of Trifolium repens varied from 10 to 45 percent, depending on the time of collection. The average percentage of sugar in alfalfa nectar in Utah was 40 percent in an experiment conducted by Vansell (1946).

The effects of fertilizers on nectar and alfalfa seed production was studied by Nickelson (1949). His results indicated that there were no significant differences in nectar following different treatments, with one exception — plants where a combination of nitrogen, phosphorus, and potassium was applied appeared to produce less nectar than flowers on the control plots. Pedersen (1951) found no effect of fertilizers containing nitrogen, phosphorus, or the trace elements — manganese, copper, boron, or zinc — on the volume of nectar produced. Schontag (1952) did not find sugar secretion increased in individual flowers when nitrogen, phosphorus, and potassium were applied to the soil, but observed a 3- to 33-fold increase in the number of flowers formed after manurial treatments, so that the total quantity of sugar secreted by each plant was increased.

Nectar yields were 20 to 40 percent higher on areas with low nitrogen levels than on areas with higher levels in investigations by Shuel and Pedersen (1952). They proposed two possibilities for increasing the amount of nectar: (1) improving the environment and (2) improving the plant through breeding; plant breeding was suggested as the more promising. They recommended that selection be made first for seed yield and desirable agronomic characters, then that nectar yield be improved by crossing strains yielding large amounts of nectar with plants containing desirable agronomic characters.

METHODS AND MATERIALS

In 1950 four alfalfa fields, each between 10 and 15 acres in size, were selected for observation, but in 1951 a single 28-acre field, half alfalfa and half red clover, was used.

Methods and materials that were the same in 1950 and 1951 are discussed in the section, "General Methods and Materials Used in 1950 and 1951." Details of different methods and materials used during the 2 years are discussed in separate sections.

General Methods and Materials Used in 1950 and 1951

To facilitate sampling, the 1950 and 1951 experimental fields were divided into units designated as blocks. Square-yard quadrats, referred to as plots, were placed according to a random plan within the blocks and these plots were used throughout the season as sampling areas for observing honey bees, estimating seed yields, and evaluating some of the other variables considered. The plots were made by using one full-length lath and three half-length laths as corners and using a string to delimit the margins of the square-yard areas. Numbers were written on the full-length lath to identify each plot (Figure 6).

Two observers followed a randomly selected schedule of visits and made simultaneous observations in the experimental fields in 1950, but one observer recorded nearly all the data taken in 1951.

Honey bees and other pollinators

Colonies of honey bees were moved into two of the four fields used

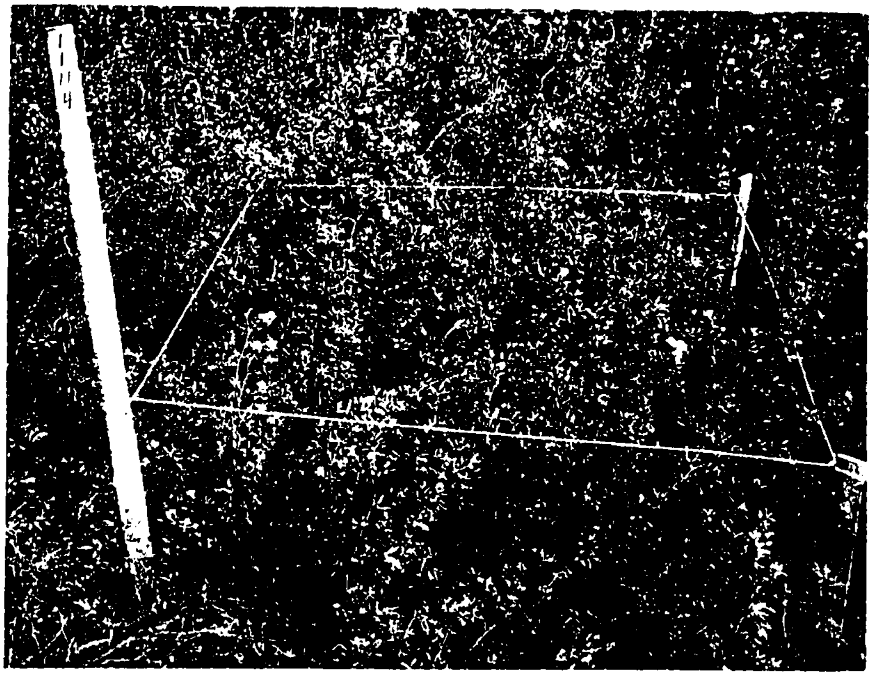


Fig. 6. Square-yard plot used as the sampling unit in 1950 and 1951.

for study in 1950 and into the single experimental field in 1951; the hives were left in the same positions throughout the studies. Besides counting the bees present in plots, observers attempted to record the activities of certain bees within the boundaries. When bees could not be found inside the plots, those nearest the plots were observed. Further details of methods used in recording bee activities are given in the discussion of methods for each year. A survey of the number of honey bee colonies located within a 2-mile radius of each experimental field was made both years.

Injurious insects

Insecticides were applied to the 1950 experimental fields to eliminate the influence of injurious insects on seed yields. An insect net was used to sample the kinds and numbers of injurious insects present. These insect surveys showed that prebloom applications did not control the insects adequately. Therefore, it was necessary to apply insecticides after the plants flowered, but these materials were applied at night or early morning before pollinating insects were in the fields. The same insecticides were applied at the same rates on the experimental fields except Farm Service. Insecticides were applied with airplane or ground sprayers.

In 1951 a study of several insecticides for control of injurious insects was combined with the pollination studies.

Climatological data

The instruments used to record various kinds of climatological data are shown in Figures 7, 8, 9, 10, and 11. In 1950 a sling psychrometer was used to measure relative humidity and temperature (Figure 7). A hygrothermograph for recording both relative humidity and temperature was placed in a weather shelter in the experimental field in 1951 (Figure 8). Livingston atmometers (Figure 9) were used for evaluating evaporation during both years, but the data for 1950 were not suitable for analysis.

Two different instruments were used for measuring wind velocity. The fan-type anemometer shown in Figure 10 was used in making most of the observations in 1950; a cup-type anemometer (Figure 8) was used to measure wind velocity in 1951. Both wind velocity and wind direction were observed during the time bees were counted. Light intensity was measured with the Weston light meter shown in Figure 11.

Agronomic data

Plant characteristics and location. When it became evident during the 1950 studies that, to a large extent, honey bees were not working in the fields in which they were placed, a survey was made to determine which plants might be attracting the honey bees from the alfalfa. Maps indicating the approximate number of acres and locations of these competing crops were made for an area within a 2-mile radius of each of the experimental fields in both 1950 and 1951.

Plant characteristics and location of plants in the fields as related to honey bee populations and seed yields were studied for two reasons: (1) to obtain information that would assist in interpreting seed yields and (2) to obtain data for checking theories which have

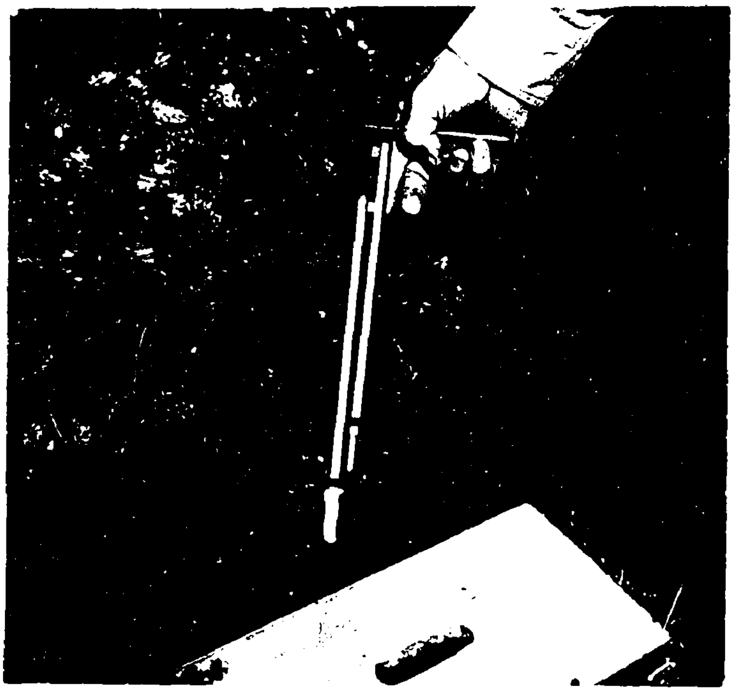


Fig. 7. Sling psychrometer used to determine air temperature and relative humidity.

Fig. 8. Weather shelter housing hygrothermograph (center) and cup-type anemometer (right), Agricultural Engineering Farm. Ames, 1951.

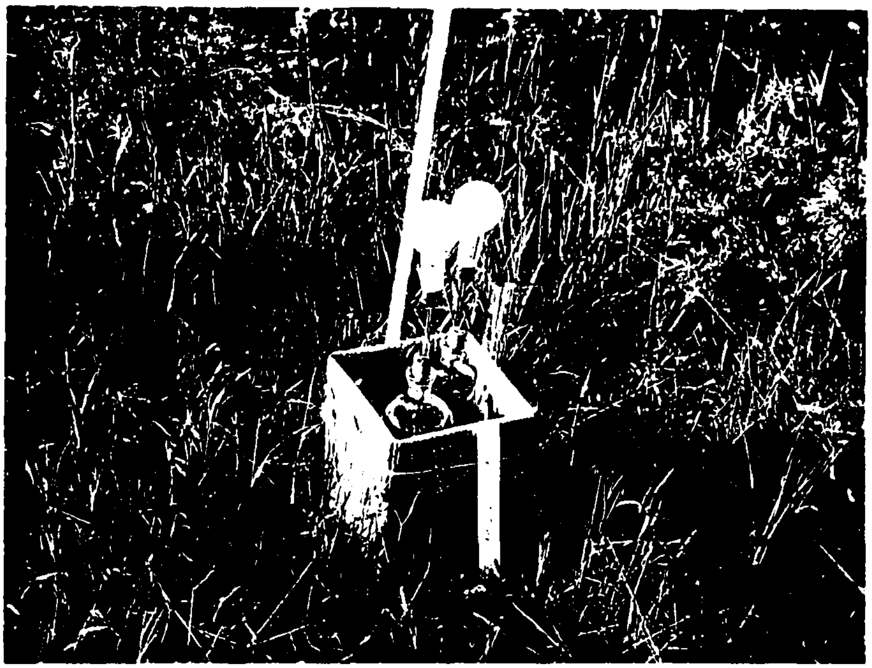


Fig. 9. Livingston atmometers used for evaluating daily evaporation of moisture.

Fig. 10. Fan-type anemometer used for measuring wind velocity in 1950.

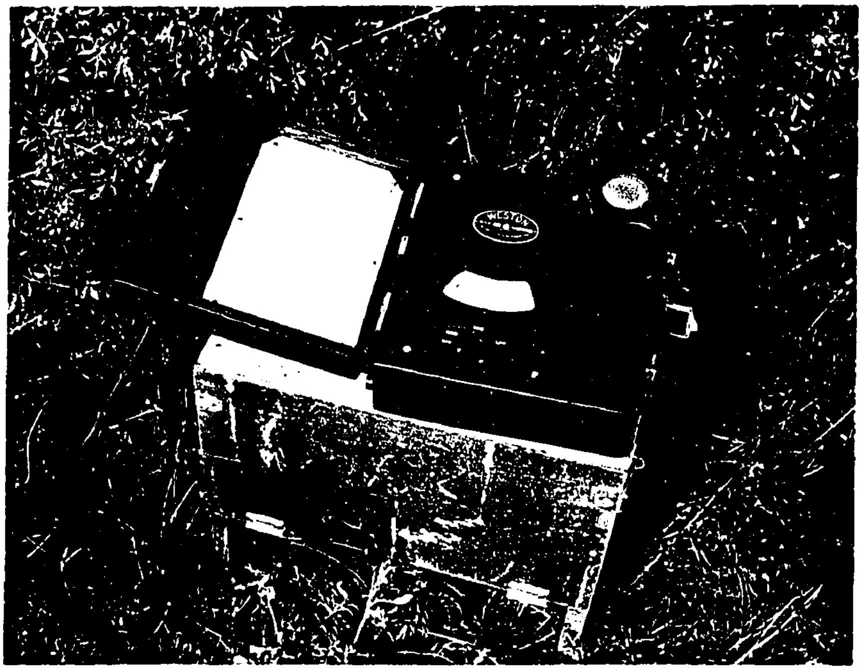


Fig. 11. Weston light meter used for measuring light intensity.

proposed that good seed yields are associated with short plants, thin stands, and alfalfa located on knolls or high ground.

Plant height in inches, plant stand, and relative elevation (topographical location) of each square-yard plot were evaluated. The rating scale for stand included a range of values from one to four, based on the number of plants and the kind of vegetation found in each square-yard plot. The ratings were:

1 = 20-200 stems

2 = 200-400 stems, with no apparent regrowth from the crowns

3 = 200-400 stems, with at least some regrowth from crowns

4 = 400 or more stems per plot

Elevation was evaluated by using a rating scale of one to six. A value of one represented the lowest spot in the field, and six represented the highest. The ratings were comparable within the same field but not between fields, because each value was relative to differences of elevation within a particular field. Differences in elevation were measured or estimated in feet where it seemed reasonable to expect there might be differences in various factors because of the topography. The rating scale can, therefore, also be interpreted in feet in some fields.

Soil analyses. Soil samples taken from 480 square-yard plots in 1950, and 336 plots in 1951 were analyzed for available phosphorus, available potassium, and pH by the Iowa State College Soil Testing Laboratory. Methods of making the soil analyses were described by Hanway and Heidel (1952).

The soil samples were taken with an auger and consisted of composited borings each 1 inch in diameter and 6 inches deep from the soil surface. Two borings were taken from each of the square-yard plots and the borings from all plots in a block were composited to make the sample representing the block.

Seed yields. Estimates of seed yields were based on the amount of seed harvested from the individual square-yard plots. After each plot was harvested, the plants were placed in a paper bag to dry. A Vogel threshing machine was used to remove the pods from the plants and a custom-built, belt-type thresher to remove the seed from the pods.

An Office Clipper was used to clean the seed samples. Some of the seed samples, however, contained large quantities of weed seeds that could not be removed with the machinery available. Therefore, 1-gram samples of the seed from each plot were cleaned by hand, and the final yield was calculated in terms of clean seed. Seed yields were converted from grams per plot to pounds per acre.

Statistical analyses

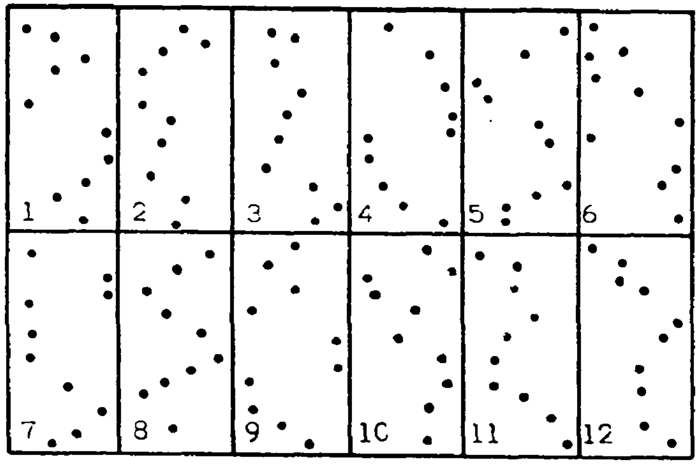
Data from square-yard plots were composited into block averages and then punched on IBM cards for statistical analysis. Principal analyses were made by the Iowa State College Statistical Laboratory.

Procedure in 1950 Experiments

To determine the contribution of honey bees to alfalfa seed production, the experimental plan shown in Figure 12 was designed. Four fields, approximately 7 miles apart, were selected for the study; four colonies of bees per acre, based on the acreage of the experimental field, were

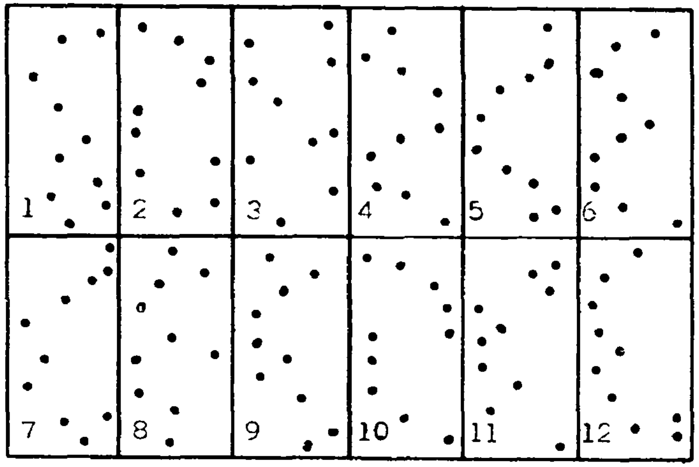
Fig. 12. Field plans for alfalfa seed production experiments, Ames, 1950. These diagrams do not represent the comparative sizes nor shapes of the four fields. The numbered areas represent the blocks and the dots show random location of 10 square-yard plots within each block.

LOCATION I
Farm Service Field



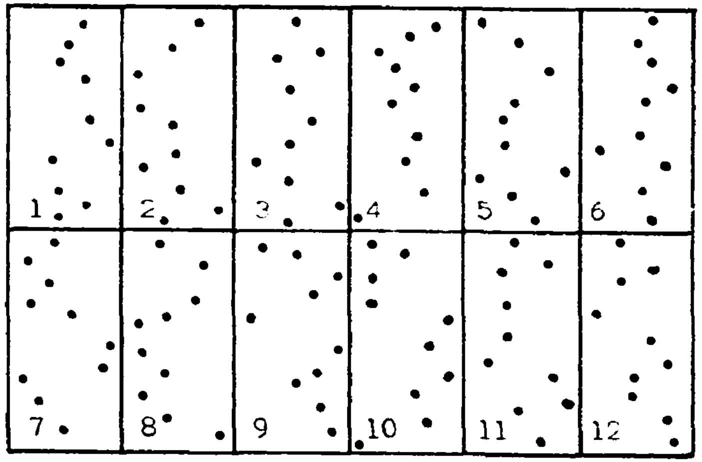
check

Dalton Field



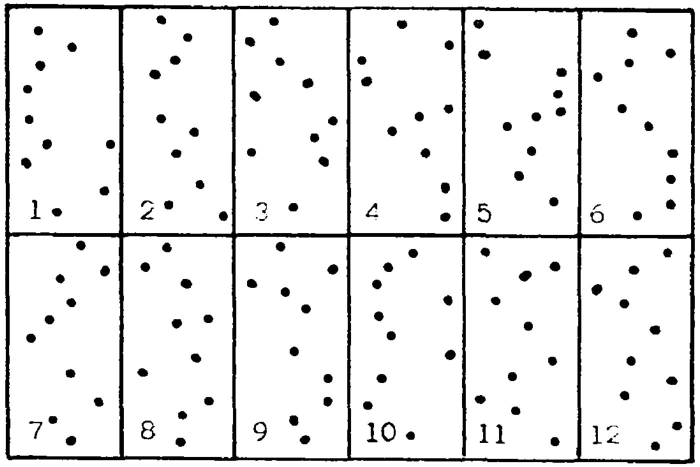
four colonies of bees per acre

LOCATION II
Danks Field



check

Severtson Field



four colonies of bees per acre

placed in two of the fields but honey bees were not placed in the other two. Each field was divided into 12 blocks, and within each block 10 square-yard plots were randomly distributed (Figures 12 and 13). The field plan in Figure 12 is diagrammatic in that it does not represent the actual shapes of the four fields nor their comparative sizes.

Farm Service field

The alfalfa field shown in Figures 14 and 15 was located about one-half mile south of Lincoln Way on Beech Avenue in Ames and was operated by the Farm Service of Iowa State College. There were approximately 14 acres in the field, and the blocks measured 224 by 230 feet. Bees were not moved into this field for the experiment. The topography of this field was more irregular than that of any of the others, the west side of the field being approximately 40 feet higher than the east side. There was an excellent stand of alfalfa over the entire field. Along the east side of this field there was a large field of corn and alfalfa, and an oat field bordered it on the west. Corn and a hog pasture were present along the north end, and Atlas sorgo was grown along the south end.

Dalton field

The Dalton field (Figure 16) was located 7 miles southeast of Ames and covered approximately 15 acres; the blocks were about 165 by 334 feet. A total of 60 colonies of bees were moved into the field on July 17, 18, 19, and 21. The field was fairly level but had several low spots near the center and across the width of the field. The stand of alfalfa

Fig. 13. Distribution of square-yard sampling units or plots, Dalton field. Ames, 1950.

Fig. 14. Farm Service field. Ames, 1950.

Fig. 15. Variability in elevation at Farm Service field. Ames, 1950.

Fig. 16. Dalton field. Ames, 1950.

toward the north end of the field was better than that on the south. The field was bounded on the east and west by corn, on the north by farm buildings, and on the south by alsike clover.

Danks field

The Danks field, which covered approximately 10 acres, was located 7 miles west and 1 1/2 miles south of Ames (Figure 17); the blocks in this field were 158 by 230 feet. As indicated in the field plan (Figure 12), honey bees were not moved into this field. The Danks field had only slight variations in topography; there was an excellent stand of alfalfa. Corn bordered the plots on the west and south, farm buildings on the east, and small grain on the north.

Severtson field

The 10-acre Severtson field (Figure 18) was located 3 miles west and 6 miles south of Ames; the blocks were 126 by 315 feet. Forty colonies of honey bees were moved into this field during the week of July 23 to 28. The topography of this field was more irregular than the Dalton field, but less so than the Farm Service field. There was a large knoll in the center of the Severtson field. Throughout the field there was a thin but even stand of alfalfa. Crops in the surrounding area were: corn on the west, red clover on the east, small grain on the north, and red and alsike clovers on the south.

Methods of randomizing and making observations

In order to reduce the variation that might result from having two observers and from making observations at different times, a plan for

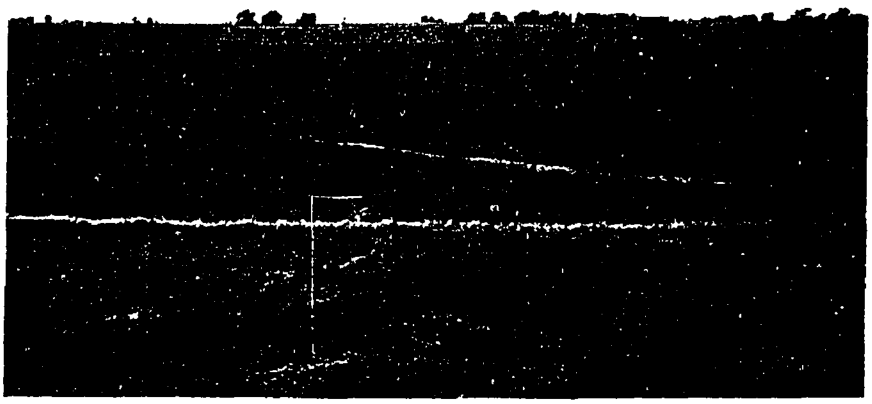


Fig. 17. Danks field. Ames, 1950.

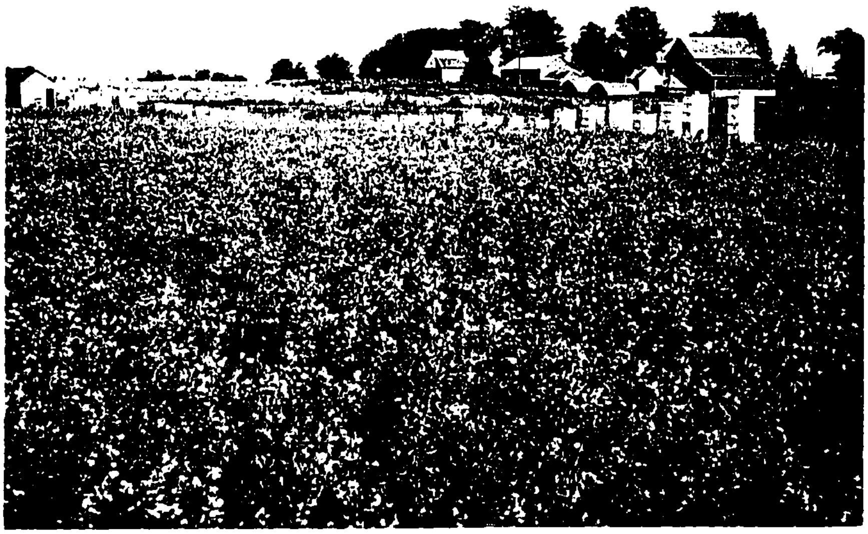


Fig. 18. Severtson field. Ames, 1950.

the season was made whereby the field to be visited by a particular observer and the date and time of day the visit was to be made were selected at random. The random plan included the following provisions and restrictions:

1. All 480 square-yard plots in the four fields were to be observed during each of a series of 2-day observation periods. Half of the plots were to be visited each day of the 2-day cycle.

2. Each field was to be visited an equal number of times during four daily time periods designated as: first in the morning, second in the morning, first in the afternoon, and second in the afternoon.

3. Each observer was to visit all blocks in the four fields an equal number of times during the experiment.

The following is a typical schedule for making the observations. If, according to the prearranged randomized plan, Observer A had been selected to visit the Farm Service field in Location I during the first morning period, then Observer B would go to the Dalton field (Figure 12). After spending approximately 2 hours observing 30 plots, the observers would exchange fields for the second morning period. Observer A would then make observations in the Dalton field comparable to those he had made earlier in the Farm Service field. Conversely, Observer B would make parallel observations in the Farm Service field during the second morning period. The same procedure was followed in Location II during the two time periods in the afternoon. In this way 60 plots, or half of those in each field, were observed the first day. The remaining plots were observed on the second day of the 2-day period. The observation days were not always consecutive because of weather and other conditions.

The usual procedure followed by each of the observers upon his arrival at a field was:

1. Honey bees and other pollinators were counted in the 10 square-yard plots in each of the three blocks that had been randomly selected, a total of 30 plots. Stop watches were used for accurate timing, and Veeder tallies were employed for fast and accurate counting. The observation time on each plot did not exceed 1 minute.

2. Five of the 10 plots previously selected in each block were observed and records were made of the following:

   a. Activities of one honey bee for 30 seconds: the number of flowers visited, the number tripped, and whether the bee was collecting pollen or nectar

   b. Direction and velocity of wind

   c. Light intensity (the amount of light reflected from a white blotter)

3. Relative humidity and temperature were measured with a sling psychrometer before observations on each block were begun.

Injurious insects

One objective of this study was to eliminate injurious insects as a major factor in seed production. Frequent surveys of injurious insects were made, and insecticides were applied in an effort to keep the number of injurious insects as near zero as possible. The principal use of the insect surveys was to determine when insecticide should be applied.

Table 1. Control of injurious insects in four fields. Ames, 1950.

Date	Field	Insecticide used and rate of application per acre	Kind of sprayer
July 4	Dalton	DDT, 1 1/2 lbs.	Airplane
July 5	Severtson	DDT, 1 1/2 lbs.	Ground
July 5	Danks	DDT, 1 1/2 lbs.	Ground
July 17	Farm Service	DDT, 1 lb., and toxaphene, 1 1/2 lbs.	Ground
August 7	Dalton	Toxaphene, 1 1/2 lbs.	Airplane
August 8	Farm Service	Toxaphene, 1 1/2 lbs.	Ground
August 8	Severtson	Toxaphene, 1 1/2 lbs.	Airplane
August 8	Danks	Toxaphene, 1 1/2 lbs.	Airplane

Table 1 shows the dates on which insecticides were applied, the kind of insecticides used, and the rates and methods of application.

Procedure in 1951 Experiments

Agricultural Engineering field

In the spring of 1950 a 28-acre field located on the Agricultural Engineering Research Farm at Ames was seeded for studies to be conducted in 1951. Half the field was planted with red clover and the other half with alfalfa, as is shown in the field plan (Figure 19). The field was divided into 68 blocks about 1/3 acre each; 16-foot brome grass border separated the blocks (Figure 20). Six square-yard plots, similar to

Fig. 19. Field plan for Agricultural Engineering field. Ames, 1951.

Key to field plan:

A - Check, no insecticide applied
B - Methoxychlor, 2 pounds per acre
C - Aldrin, 1/4 pound per acre, plus DDT, 1 pound per acre
D - Toxaphene, 1 1/2 pounds per acre, plus DDT, 1 pound per acre

I, II, III, IV - Replications

a - First crop seed
b - Second crop seed

1 to 68 - Block numbers*

---

*Blocks 33, 34, 35, and 36 were used in a preliminary study not reported in this paper. Blocks 39, 43, 47, 51, 55, 59, 62, and 67 were eliminated from the experiment because of injury by excess moisture (see Figure 20).

	1 B-I-a	2 D-II-a	3 C-I-b	4 B-II-b
	5 C-I-a	6 B-II-a	7 D-I-b	8 D-II-b
	9 A-I-a	10 A-II-a	11 B-I-b	12 C-II-b
	13 D-I-a	14 C-II-a	15 A-I-b	16 A-II-b
ALFALFA	17 B-III-b	18 C-IV-b	19 A-III-a	20 B-IV-a
	21 D-III-b	22 B-IV-b	23 C-III-a	24 C-IV-a
	25 A-III-b	26 D-IV-b	27 B-III-a	28 D-IV-a
	29 C-III-b	30 A-IV-b	31 D-III-a	32 A-IV-a
	Sugar spray experiment...second crop...aldrin,DDT applied once 33 I	34 II	35 III	36 IV
	37 D-I-a	38 A-II-a	39 Out	40 D-I-b
	41 A-I-a	42 D-II-a	43 Out	44 A-I-b
	45 B-I-a	46 B-II-a	47 Out	48 B-I-b
	49 B-II-b	50 D-III-b	51 Out	52 D-III-a
RED CLOVER	53 D-II-b	54 B-III-b	55 Out	56 A-III-a
	57 A-II-b	58 A-III-b	59 Out	60 B-III-a
	61 A-IV-b	62 Out	63 B-IV-a	64 D-IV-a
	65 B-IV-b	66 D-IV-b	67 Out	68 A-IV-a

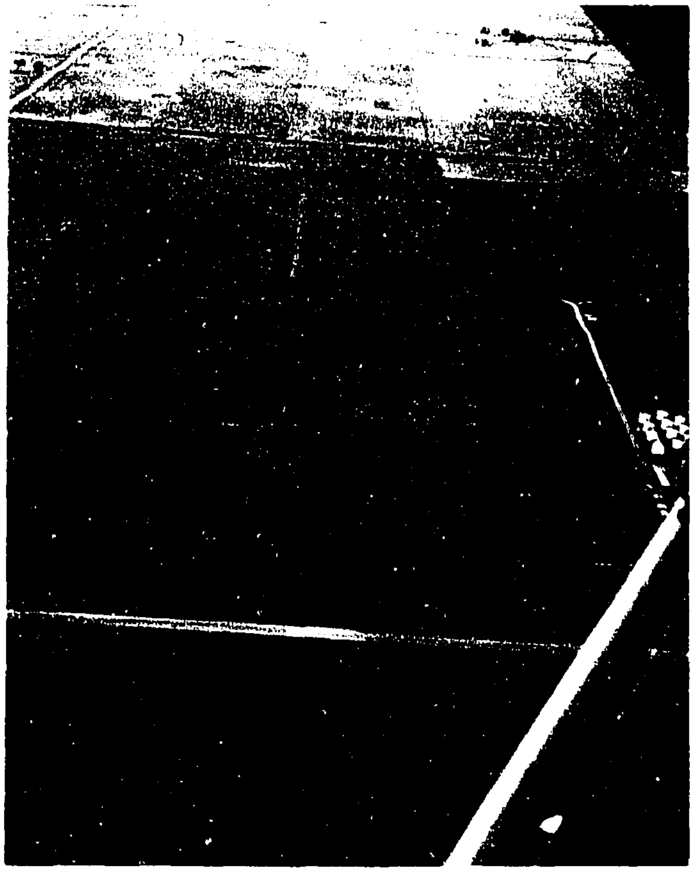


Fig. 20. Aerial photograph of experimental field at Agricultural Engineering Research Farm. Ames, 1951. Block No. 1 is in the upper left corner; brome grass strips delineate the blocks. Darker area in foreground is red clover; clover in irregular shaped area was destroyed by excess moisture. Lighter area is alfalfa. Honey bee colonies placed in the field can be seen in four small groups.

those illustrated in Figure 6, were placed at random in each block. Half of the alfalfa and half of the red clover was left for first crop seed; the other half of each crop was cut for hay in June and was harvested later for second crop seed. Studies made on blocks 33 through 36 were not considered for this thesis.

On June 22, 26 colonies of honey bees were moved into the field and left until flowering had ceased. The four groups of colonies in the field are barely visible in Figure 20.

A study of three insecticide treatments and their effectiveness in controlling injurious insects of alfalfa was conducted in conjunction with the pollination studies. The insecticides tested, the rates at which they were applied, and the locations of the several treatments are shown in Figure 19.

Methods of randomizing and making observations

The method of randomizing the times and places of observations was similar to that used in 1950, but there were a few minor changes in 1951 due to the fact that there were two crops, red clover and alfalfa. By random selection it was decided which crop to visit first in the morning and first in the afternoon. The crop not selected for the first visit was automatically indicated for the second visit of the respective half-day periods. This random selection was restricted to the extent that each crop was visited an equal number of times in each of the four daily time periods.

The study was so arranged that all plots of both crops were visited in a 2-day time period, half of the plots being visited each day of this

2-day cycle. Plots not selected for observation on Day I were observed on Day II. There were some occasions when these two days were not consecutive. Daily observations were made by only one observer in 1951, and with few exceptions they were made by the writer. So few observations were made on the first crop alfalfa and red clover that the data were only partially analyzed. All second crop plots were observed eight times during the period July 25 to August 27, which represents a total of 16 observation days or eight 2-day time periods.

After the plots to be observed had been selected, the procedure was as follows:

1. Honey bees and other pollinators in the six square-yard plots within each block of a replication were counted. Observation time on each plot did not exceed 1 minute.

2. At three of the six plots observed, records were made of the following:

    a. Activities of one honey bee for 30 seconds: the number of flowers visited, the number of flowers tripped, and whether the bee was collecting pollen or nectar

    b. Light intensity

3. Relative humidity and temperature were determined by use of a sling psychrometer at the beginning of observations on each replication of red clover and on the first and third blocks in each replication of alfalfa. Extra determinations were made if the time required to make the observations was extended beyond 20 minutes.

4. Wind velocity was based on readings from a cup-type anemometer,

and the value used was the average wind velocity during the time observations were made on a replication.

5. Evaporation, as shown by the atmometers, was recorded in the morning, at noon, and at the close of an observation day.

Injurious insects

The kinds and numbers of injurious insects present on each block were determined once each week by sweeping the alfalfa and red clover with an insect net. Insects were either counted in the field or placed in containers and counted later in the laboratory. From 10 sweeps made on each block during these surveys, fluctuations in the numbers of the following insects were recorded: lygus bugs, leafhoppers, alfalfa plant bugs, rapid plant bugs, and grasshoppers.

The entire field except the check blocks was sprayed three times with insecticides; Table 2 gives the dates on which the sprays were applied. All insecticides were applied with a ground sprayer. The kinds

Table 2. Dates insecticides were applied to first and second crops alfalfa and red clover. Agricultural Engineering field, Ames, 1951.

Crop	Date
First crops alfalfa and red clover	June 3 June 19 July 7
Second crops alfalfa and red clover	July 7 July 19 August 11

and amounts of insecticides used are indicated in Figure 19.

Plant analyses

Alfalfa plants for analysis were collected at random throughout the blocks when the plants were just coming into bloom. After being placed in paper bags and allowed to dry, each sample was pulverized in a hammer mill and sent to the Department of Agronomy for analysis. The method of analysis was described by Hanway (1954).

Nectar studies

During the 1950 studies it became apparent that only a few honey bees were remaining in the alfalfa fields and that those which did remain were pollinating only a small number of the flowers visited. As a result, Dr. O. W. Park of the Department of Zoology and Entomology agreed to direct studies on nectar quantity and quality to see if nectar might be associated with the number of bees found or their activities on alfalfa. Nectar data taken on a field basis in 1950 were unsuitable for comparison with other data based on block averages; therefore, they have been omitted from this dissertation. However, similar nectar studies made by Dr. Park and his associates in 1951 are included because the data are comparable.

Bees collected for nectar studies in 1951 were taken from individual blocks, and the data were recorded on this basis. As a rule, these bees were collected from the same blocks and at about the same time as data were obtained on other items.

The procedure used in collecting the nectar samples was as follows: During the time the honey bees were being counted, other personnel collected honey bees from the same area. Honey sacs were removed from the bees and the size of the nectar load was classified as none, small, medium, or large. The percentage of sugar contained in each load of nectar was determined by use of an Abbe refractometer. In addition to the quantity and quality of nectar, records were made of the following: time of day, temperature, relative humidity, time required to collect bees, size and color of pollen loads, the number of bees that had to be examined to obtain 10 nectar samples that were adequate for analysis, and whether the bees carried pollen only, nectar only, both, or neither.

RESULTS AND DISCUSSION

1950 Experiments

In 1950 experiments for determining the value of honey bees in pollinating alfalfa were conducted on four fields. Each field was divided into 12 blocks with 10 randomly selected square-yard plots within each block, making a total of 120 plots for each field and 480 for the 1950 experiments.

The number of bees present on each of the 480 square-yard plots was counted eight times between July 29 and August 23. Pollinating activities of honey bees and weather conditions were evaluated each time the bees were counted, but only one observation per plot was made during the season on such variables as seed yield, stand, elevation, plant height, soil pH, available phosphorus, and available potassium.

Most of the data obtained from the 10 plots of each block were combined into an average for the block, and in this way data such as those on honey bee populations were reduced from 3,840 observations (480 plots x 8 observations = 3,840) to 384 observations for statistical analysis.

Means for all 1950 data are summarized in Table 3 and Tables 4 through 7 give the block averages for each field separately. The analyses of variance for the factors considered are given in Tables 8 and 9, and correlation coefficients are presented in Tables 10 and 11. Table 12 presents the average within-field regression equations (error regression equations) for all variables considered, and includes the correlation coefficients as a convenience for (text continued on page 87)

Table 3. Summary of field means of variables considered in study of alfalfa seed production in four fields. Ames, 1950.

Factor studied	Location I: Farm Service[a]	Location I: Dalton[b]	Location II: Danks[a]	Location II: Severtson[b]	Average
Honey bee populations (no./10 sq. yds.)	17.4	11.6	17.5	16.5	15.8
Honey bee activity					
No. flowers visited/30 secs.	8.0	7.9	8.5	8.1	8.2
Climatological factors					
Wind velocity (mph)	3.5	2.7	3.6	3.7	3.4
Light (10 ft. candles)	380	380	426	423	402
Air temperature (° F.)	80.6	80.3	79.6	79.4	80.0
Relative humidity	59.9	60.9	60.3	61.4	60.7
Vapor pressure deficit	11.0	10.5	10.6	10.2	10.6
Agronomic factors					
Stand (1-4)	3.1	2.5	2.3	2.8	2.6
Elevation (1-6)	3.3	2.0	2.0	2.2	2.4
Plant height (in.)	37	30	28	31	32
Soil pH	6.6	6.8	6.9	7.0	6.8
Available P (lbs./A.)	19.0	1.5	6.9	1.2	7.2
Available K (lbs./A.)	165	109	164	120	140
Seed yield (lbs./A.)	168	94	140	90	123

[a]No bees moved into field

[b]Four colonies of bees per acre moved into field

Table 4. Block means for variables studied, Farm Servic

Block no.	Honey bee populations (no./10 sq. yds.)	No. flowers visited by honey bees (per 30 secs.)	Climatological factors: Wind velocity (mph)	Light (10 ft. candles)	Air temperature (°F.)	Relative humidity	Vapor pressure deficit	Stand (1-4)	El t (
1	17.6	8.3	3.1	373	82.1	63.5	10.2	4	
2	16.6	8.2	3.2	355	80.1	59.0	11.2	3	
3	15.4	8.1	4.4	468	79.2	62.0	9.6	4	
4	17.1	8.2	2.3	382	81.8	62.5	10.2	3	
5	14.0	7.9	2.9	404	78.5	62.0	9.8	3	
6	14.8	8.2	2.9	344	80.2	57.5	12.5	3	
7	12.2	7.9	4.3	361	77.4	61.6	10.2	3	
8	19.6	8.8	4.8	304	84.6	53.1	14.4	3	
9	16.2	7.6	4.3	329	79.0	65.8	8.8	3	
10	22.5	7.7	3.9	398	81.5	53.2	13.2	3	
11	24.4	8.2	3.2	433	81.6	54.0	12.3	3	
12	18.6	7.4	2.3	408	80.8	65.1	9.7	2	
Average	17.4	8.0	3.5	380	80.6	59.9	11.0	3.1	

ns for variables studied, Farm Service field. Ames, 1950.

logical factors			Agronomic factors						
						Soil			
Air temperature (°F.)	Relative humidity	Vapor pressure deficit	Stand (1-4)	Elevation (1-6)	Plant height (in.)	pH	Available P (lbs./A.)	Available K (lbs./A.)	Seed yield (lbs./A.)
82.1	63.5	10.2	4	2	42	6.4	30.0	192	137
80.1	59.0	11.2	3	2	38	6.4	10.5	132	158
79.2	62.0	9.6	4	2	37	6.3	10.5	128	126
81.8	62.5	10.2	3	3	40	6.6	10.0	132	192
78.5	62.0	9.8	3	3	36	6.6	7.0	144	175
80.2	57.5	12.5	3	3	31	7.0	15.0	164	129
77.4	61.6	10.2	3	4	39	6.7	30.0	240	159
84.6	53.1	14.4	3	4	39	7.4	30.0	244	181
79.0	65.8	8.8	3	3	38	7.0	6.0	100	153
81.5	53.2	13.2	3	5	35	6.4	18.0	140	229
81.6	54.0	12.3	3	6	36	6.4	33.0	208	233
80.8	65.1	9.7	2	2	33	6.4	28.0	156	149
80.6	59.9	11.0	3.1	3.3	37	6.6	19.0	165	168

Table 5. Block means for variables studied, Dalton f

Block no.	Honey bee populations (no./10 sq. yds.)	No. flowers visited by honey bees (per 30 secs.)	Climatological factors: Wind velocity (mph)	Light (10 ft. candles)	Air temperature (°F.)	Relative humidity	Vapor pressure deficit	Stand (1-4)
1	14.2	9.0	2.5	480	82.1	59.1	11.9	3
2	14.0	7.8	2.8	433	79.4	65.1	9.3	3
3	16.4	8.2	3.3	400	79.4	59.6	10.4	2
4	14.6	7.8	2.3	346	80.2	62.4	10.0	3
5	6.6	8.3	2.9	411	80.9	63.4	9.8	2
6	5.2	7.6	3.9	381	78.8	63.6	9.8	2
7	11.2	7.3	2.2	230	81.0	59.0	10.9	3
8	12.9	8.1	2.8	392	78.8	67.0	7.8	2
9	13.4	7.6	2.2	399	78.1	61.4	10.0	2
10	13.0	7.6	2.2	326	79.4	57.8	10.9	3
11	10.1	7.6	1.9	408	82.2	59.0	11.9	2
12	7.8	8.1	3.9	351	83.1	54.0	13.4	2
Average	11.6	7.9	2.7	380	80.3	60.9	10.5	2.5

k means for variables studied, Dalton field. Ames, 1950.

limatological factors				Agronomic factors							
ght ft. iles)	Air temperature (°F.)	Relative humidity	Vapor pressure deficit	Stand (1-4)	Elevation (1-6)	Plant height (in.)	Soil			Seed yield (lbs./A.)
							pH	Available P (lbs./A.)	Available K (lbs./A.)	
)	82.1	59.1	11.9	3	2	34	7.0	2.0	116	77
5	79.4	65.1	9.3	3	2	36	6.3	2.5	120	104
)	79.4	59.6	10.4	2	2	34	6.2	2.5	112	129
5	80.2	62.4	10.0	3	2	34	6.2	2.5	120	120
.	80.9	63.4	9.8	2	2	21	7.5	1.0	96	68
.	78.8	63.6	9.8	2	2	21	7.9	1.0	112	35
)	81.0	59.0	10.9	3	1	36	6.5	1.0	108	109
2	78.8	67.0	7.8	2	3	36	6.4	1.5	112	146
)	78.1	61.4	10.0	2	2	35	6.3	1.5	100	110
5	79.4	57.8	10.9	3	2	34	6.4	1.0	104	120
3	82.2	59.0	11.9	2	2	23	6.9	1.0	108	70
.	83.1	54.0	13.4	2	2	20	8.0	1.0	100	37
)	80.3	60.9	10.5	2.5	2.0	30	6.8	1.5	109	94

Table 6. Block means for variables studied, Danks fi

Block no.	Honey bee populations (no./10 sq. yds.)	No. flowers visited by honey bees (per 30 secs.)	Climatological factors: Wind velocity (mph)	Light (10 ft. candles)	Air temperature (°F.)	Relative humidity	Vapor pressure deficit	Stand (1-4)
1	18.2	8.1	3.7	366	77.4	64.6	8.7	2
2	18.9	8.7	4.4	421	81.5	56.8	12.0	2
3	20.6	9.2	3.3	569	81.9	56.4	12.3	3
4	13.9	8.6	3.9	466	80.9	60.0	11.2	2
5	26.8	9.8	3.9	554	78.1	61.4	9.5	3
6	14.5	8.2	3.6	520	78.2	66.6	8.7	3
7	15.6	8.3	3.4	399	78.4	64.0	9.0	2
8	11.1	8.7	3.4	387	82.4	54.0	13.2	1
9	15.1	8.6	3.3	375	78.4	55.8	12.0	2
10	19.9	8.2	3.7	354	79.6	62.6	10.0	2
11	17.4	8.3	3.3	332	79.5	60.4	10.9	3
12	17.6	8.0	3.5	370	79.4	61.6	10.1	3
Average	17.5	8.5	3.6	426	79.6	60.3	10.6	2.3

means for variables studied, Danks field. Ames, 1950.

	atological factors			Agronomic factors						
							Soil			
. s)	Air temperature (°F.)	Relative humidity	Vapor pressure deficit	Stand (1-4)	Elevation (1-6)	Plant height (in.)	pH	Available P (lbs./A.)	Available K (lbs./A.)	Seed yield (lbs./A.)
	77.4	64.6	8.7	2	2	27	6.3	2.0	92	160
	81.5	56.8	12.0	2	2	26	6.3	1.0	116	160
	81.9	56.4	12.3	3	2	30	6.3	2.0	112	147
	80.9	60.0	11.2	2	2	23	7.0	1.0	128	98
	78.1	61.4	9.5	3	2	31	6.4	12.0	268	173
	78.2	66.6	8.7	3	2	30	6.4	8.0	220	216
	78.4	64.0	9.0	2	2	26	8.0	1.0	128	123
	82.4	54.0	13.2	1	2	20	7.6	1.0	108	90
	78.4	55.8	12.0	2	2	27	6.2	2.0	136	169
	79.6	62.6	10.0	2	2	30	7.0	6.0	136	148
	79.5	60.4	10.9	3	2	32	7.8	3.5	264	103
	79.4	61.6	10.1	3	2	35	7.6	44.0	264	97
	79.6	60.3	10.6	2.3	2.0	28	6.9	6.9	164	140

Table 7. Block means for variables studied, Severts

Block no.	Honey bee populations (no./10 sq. yds.)	No. flowers visited by honey bees (per 30 secs.)	Climatological factors: Wind velocity (mph)	Light (10 ft. candles)	Air temperature (°F.)	Relative humidity	Vapor pressure deficit	Sta (1-l
1	14.5	8.2	3.1	458	77.2	67.9	7.9	3
2	17.2	8.1	4.8	426	82.1	55.0	13.0	3
3	15.2	8.1	3.1	359	79.1	60.2	10.3	3
4	15.8	7.7	4.1	481	79.6	59.1	10.2	3
5	18.0	8.2	4.1	441	77.8	65.2	8.5	3
6	19.1	8.7	2.8	461	78.4	62.1	9.5	2
7	13.0	8.1	3.8	441	80.9	57.9	11.5	3
8	14.0	7.6	3.9	434	79.8	59.5	11.3	3
9	16.9	7.9	4.2	344	80.8	62.4	10.4	2
10	19.4	8.4	3.2	442	80.0	58.6	10.8	3
11	13.8	7.6	3.1	389	77.4	64.2	8.8	3
12	21.6	8.8	3.9	405	79.5	65.1	9.1	2
Average	16.5	8.1	3.7	423	79.4	61.4	10.2	2.8

eans for variables studied, Severtson field. Ames, 1950.

ological factors			Agronomic factors						
						Soil			
Air temperature (°F.)	Relative humidity	Vapor pressure deficit	Stand (1-4)	Elevation (1-6)	Plant height (in.)	pH	Available P (lbs./A.)	Available K (lbs./A.)	Seed yield (lbs./A.)
77.2	67.9	7.9	3	2	29	8.1	1.0	88	76
82.1	55.0	13.0	3	2	33	6.5	1.0	108	62
79.1	60.2	10.3	3	2	32	6.5	1.0	112	95
79.6	59.1	10.2	3	2	31	6.3	1.0	140	88
77.8	65.2	8.5	3	2	30	7.5	1.0	136	100
78.4	62.1	9.5	2	2	27	8.0	1.0	116	92
80.9	57.9	11.5	3	2	32	8.1	1.0	112	43
79.8	59.5	11.3	3	2	31	7.6	2.5	108	67
80.8	62.4	10.4	2	3	33	6.2	1.0	132	94
80.0	58.6	10.8	3	4	32	6.7	1.0	116	106
77.4	64.2	8.8	3	2	34	6.3	2.0	152	112
79.5	65.1	9.1	2	2	31	6.6	1.5	120	147
79.4	61.4	10.2	2.8	2.2	31	7.0	1.2	120	90

Table 8. Analyses of variance by blocks of variables studied. Ames, 1950.

Source of variation	Degrees of freedom	Mean squares	F.
	Honey bee populations		
Location	1	4,720.33	6.26*
Treatment	1	8,694.08	11.54**
Treatment x location	1	4,563.01	6.06*
Blocks within fields	44	753.36	
	Rate of honey bee visits to flowers		
Location	1	9,380.01	7.74**
Treatment	1	5,611.69	4.63*
Treatment x location	1	1,507.53	1.24
Blocks within fields	44	1,211.93	
	Wind velocity		
Location	1	8,992.69	3.39
Treatment	1	22,925.02	8.65**
Treatment x location	1	12,128.52	4.58*
Blocks within fields	44	2,650.02	
	Light intensity		
Location	1	1,323.00	<1
Treatment	1	1,551,602.00	6.76*
Treatment x location	1	1,323.00	<1
Blocks within fields	44	229,534.00	
	Air temperature		
Location	1	652.68	3.62
Treatment	1	58.52	<1
Treatment x location	1	0.19	<1
Blocks within fields	44	180.27	
	Relative humidity		
Location	1	154.08	<1
Treatment	1	850.08	<1
Treatment x location	1	2.09	<1
Blocks within fields	44	997.25	
	Vapor pressure deficit		
Location	1	9,492.19	<1
Treatment	1	16,539.19	1.09
Treatment x location	1	6.02	<1
Blocks within fields	44	15,159.64	

* Significant at 5 percent probability
** Significant at 1 percent probability

Table 8. (Continued)

Source of variation	Degrees of freedom	Mean squares	F.
		Stand	
Location	1	33.34	1.80
Treatment	1	12.00	<1
Treatment x location	1	225.33	12.15**
Blocks within fields	44	18.55	
		Elevation	
Location	1	225.34	6.76*
Treatment	1	225.34	6.76*
Treatment x location	1	481.32	14.44**
Blocks within fields	44	33.33	
		Plant height	
Location	1	12,288.00	10.13**
Treatment	1	2,352.00	1.94
Treatment x location	1	18,565.34	15.31**
Blocks within fields	44	1,212.25	
		Soil pH	
Location	1	4,961.00	1.94
Treatment	1	1,633.00	< 1
Treatment x location	1	34.00	<1
Blocks within fields	44	2,552.00	
		Available phosphorus	
Location	1	2,940,300.00	7.13*
Treatment	1	10,267,500.00	24.90**
Treatment x location	1	2,669,634.00	6.47*
Blocks within fields	44	412,421.00	
		Available potassium	
Location	1	19,522.00	<1
Treatment	1	1,942,466.00	16.98**
Treatment x location	1	25,024.00	<1
Blocks within fields	44	114,383.00	
		Seed yields	
Location	1	192,660.00	2.54
Treatment	1	2,992,504.00	39.46**
Treatment x location	1	115,150.00	1.52
Blocks within fields	44	75,830.00	

* Significant at 5 percent probability
** Significant at 1 percent probability

Table 9. Analyses of variance of climatological factors by 2-day observation periods. Ames, 1950.

Source of variation	Degrees of freedom	Mean squares	F.
	Wind velocity		
Fields	3	1,835.26	4.82**
Blocks within fields	44	331.25	<1
Periods	7	7,515.11	19.73**
Periods x fields	21	752.90	1.98**
Remainder	308	380.92	
	Light intensity		
Fields	3	64,760.33	2.27
Blocks within fields	44	28,691.72	<1
Periods	7	264,973.11	9.11**
Periods x fields	21	57,131.94	1.96**
Remainder	308	29,086.41	
	Air temperature		
Fields	3	29.97	1.02
Blocks within fields	44	22.53	<1
Periods	7	515.50	21.62**
Periods x fields	21	29.43	1.23
Remainder	308	23.84	
	Relative humidity		
Fields	3	41.93	<1
Blocks within fields	44	124.66	1.24
Periods	7	939.40	9.36**
Periods x fields	21	199.04	1.98**
Remainder	308	100.37	
	Vapor pressure deficit		
Fields	3	1,084.89	<1
Blocks within fields	44	1,894.95	1.33
Periods	7	5,461.75	3.83**
Periods x fields	21	2,292.90	1.61*
Remainder	308	1,425.18	

* Significant at 5 percent probability
** Significant at 1 percent probability

Table 10. Correlation coefficients of variables studied based on seasonal block averages. Ames, 1950.

	Seed yield	Honey bee populations	Rate of honey bee visits to flowers	Light intensity	Stand	Elevation	Plant height	Soil pH	Available P
Honey bee populations	0.620**								
Rate of honey bee visits to flowers	0.105	0.378*							
Wind velocity	-0.161	-0.077	0.122						
Light intensity ..	0.114	0.231	0.438**						
Air temperature ..		0.077	0.292*						
Relative humidity		-0.090	-0.212						
Vapor pressure deficit		0.002	0.217						
Stand	0.036	0.170	0.022	0.200					
Elevation	0.434**	0.351*	0.089	0.086	-0.210				
Plant height	0.414**	0.465**	-0.046	-0.095	0.580**	-0.042			
Soil pH	-0.613**	-0.426**	0.058	-0.125	-0.158	-0.057	-0.465**		
Available P	0.003	0.232	-0.034	-0.048	0.186	0.266	0.280	0.088	
Available K	0.107	0.230	0.126	-0.006	0.375*	0.212	0.371*	0.059	0.695**

* Significant at 5 percent probability
** Significant at 1 percent probability

Table 11. Correlation coefficients of variables studied, based on block averages for 2-day observation periods. Ames, 1950.

	Wind velocity	Light intensity	Air temperature	Relative humidity	Vapor pressure deficit
Honey bee populations	0.053	0.341**	0.357**	-0.202**	0.285**
Rate of honey bee visits to flowers	0.014	0.273**	0.338**	-0.186**	0.263**
Light intensity			0.155**	-0.038	0.076
Air temperature				-0.501**	0.764**
Relative humidity					-0.906**

** Significant at 1 percent probability

Table 12. Error regression equations and correlation coefficients for variables studied. Ames, 1950.

Equation number	Regression equation[a]	Degrees of freedom	Correlation coefficients r
1	$\hat{Y}_1 = -8.6058X_1 + 152.24$	43	0.161
2	$\hat{Y}_1 = 2.2745X_6 + 117.14$	43	0.036
3	$\hat{Y}_1 = 20.7197X_7 + 73.51$	43	0.434**
4	$\hat{Y}_1 = 3.2742X_8 + 19.48$	43	0.414**
5	$\hat{Y}_1 = -33.4198X_9 + 351.88$	43	-0.613**
6	$\hat{Y}_1 = 0.0130X_{10} + 123.07$	43	0.003
7	$\hat{Y}_1 = 0.0875X_{11} + 110.96$	43	0.107
8	$\hat{Y}_1 = 6.2159X_{12} + 25.16$	43	0.620**
9	$\hat{Y}_1 = 8.3370X_{13} + 55.14$	43	0.105
10	$\hat{Y}_2 = -0.4102X_1 + 17.15$	43	-0.077
11	$\hat{Y}_2 = 0.0132X_2 + 10.45$	43	0.230
12	$\hat{Y}_2 = 0.1572X_3 + 3.19$	43	0.077
13	$\hat{Y}_2 = -0.0781X_4 + 20.50$	43	-0.090
14	$\hat{Y}_2 = 0.0046X_5 + 15.72$	43	0.002
15	$\hat{Y}_2 = 1.0842X_6 + 12.90$	43	0.170
16	$\hat{Y}_2 = 1.6709X_7 + 11.76$	43	0.352*
17	$\hat{Y}_2 = 0.3664X_8 + 4.18$	43	0.465**
18	$\hat{Y}_2 = -2.3163X_9 + 31.63$	43	-0.426**

[a] See key to X and Y values at end of table
* Significant at 5 percent probability
** Significant at 1 percent probability

Table 12. (Continued)

Equation number	Regression equation[a]	Degrees of freedom	Correlation coefficients r
19	$\hat{Y}_2 = 0.0993X_{10} + 15.05$	43	0.232
20	$\hat{Y}_2 = 0.0186X_{11} + 13.16$	43	0.230
21	$\hat{Y}_3 = 0.0824X_1 + 7.92$	43	0.122
22	$\hat{Y}_3 = 0.0032X_2 + 6.91$	43	0.438**
23	$\hat{Y}_3 = 0.0758X_3 + 2.14$	43	0.292*
24	$\hat{Y}_3 = -0.0234X_4 + 9.62$	43	-0.212
25	$\hat{Y}_3 = 0.0612X_5 + 7.55$	43	0.217
26	$\hat{Y}_3 = 0.0176X_6 + 8.15$	43	0.022
27	$\hat{Y}_3 = 0.0538X_7 + 8.07$	43	0.089
28	$\hat{Y}_3 = -0.0046X_8 + 8.35$	43	-0.046
29	$\hat{Y}_3 = 0.0398X_9 + 7.93$	43	0.058
30	$\hat{Y}_3 = -0.0019X_{10} + 8.21$	43	-0.034
31	$\hat{Y}_3 = 0.0013X_{11} + 8.02$	43	0.126
32	$\hat{Y}_4 = -0.2091X_1 + 16.47$	307	-0.053
33	$\hat{Y}_4 = 0.0153X_2 + 9.61$	307	0.341**
34	$\hat{Y}_4 = 0.5602X_3 - 29.03$	307	0.357**
35	$\hat{Y}_4 = -0.1546X_4 + 25.15$	307	-0.202**
36	$\hat{Y}_4 = 0.5779X_5 + 9.65$	307	0.285**

[a] See key to X and Y values at end of table
* Significant at 5 percent probability
** Significant at 1 percent probability

Table 12. (Continued)

Equation number	Regression equation[a]	Degrees of freedom	Correlation coefficients r
37	$\hat{Y}_5 = 0.0091X_1 + 8.17$	307	0.014
38	$\hat{Y}_5 = 0.0021X_2 + 7.36$	307	0.273**
39	$\hat{Y}_5 = 0.0894X_3 + 1.05$	307	0.338**
40	$\hat{Y}_5 = -0.0240X_4 + 9.66$	307	-0.186**
41	$\hat{Y}_5 = 0.0898X_5 + 7.25$	307	0.263**

[a] Key to X and Y values:

$\hat{Y}_1$ = Seed yield by blocks

$\hat{Y}_2$ = Honey bee populations by blocks

$\hat{Y}_3$ = Rate of honey bee visits to flowers by blocks

$\hat{Y}_4$ = Honey bee populations by by periods

$\hat{Y}_5$ = Rate of honey bee visits to flowers by periods

X_1 = Wind

X_2 = Light

X_3 = Air temperature

X_4 = Relative humidity

X_5 = Vapor pressure deficit

X_6 = Stand

X_7 = Elevation

X_8 = Plant height

X_9 = Soil pH

X_{10} = Available phosphorus

X_{11} = Available potassium

X_{12} = Honey bee populations

X_{13} = Rate of honey bee visits to flowers

** Significant at 1 percent probability

evaluating these regressions. Multiple correlation coefficients and multiple regression equations are contained in Table 13. Statistical analyses for 1950 were based on seasonal block averages, except for the analyses presented in Tables 9 and 11, which were based on the same data divided into averages for eight 2-day observation periods. Figures 21 through 24 show graphically the regression of seed yields on honey bee populations and the regressions of honey bee populations on topographical elevation, plant height, and soil pH. Figures 25 and 26 show the regression of rate of honey bee visits on light intensity and air temperature, and Figures 27 through 29 illustrate the regression of seed yields on elevation, plant height, and soil pH.

Analyses of variance, means, and simple correlations and regressions

Honey bee populations. Analysis of variance showed that mean differences in honey bee populations for locations and for treatments were significant and that there was a significant interaction between treatments and locations (Table 8). The means shown in Table 3 indicate that differences in bee populations were due principally to the low bee populations in the Dalton field and the relative homogeneity of bee populations in the other three fields. Paradoxically, bee populations in the fields which did not have colonies placed in them (Farm Service and Danks) were significantly higher than those in the fields where colonies were placed (Dalton and Severtson). Farm Service had many more bees per square yard than the Dalton field, while Danks had only a few more than Severtson. Honey bee populations on blocks within each field varied considerably, as the following data on ranges (text continued on page 103)

Table 13. Error regression equations and multiple correlation coefficients for variables studied. Ames, 1950.

Equation number	Regression equation[a]	Degrees of freedom	Multiple correlation coefficients R
1	$\hat{Y}_1 = 0.0149X_1 - 0.9060X_5 + 1.3657X_6 + 0.3729X_7 - 1.0174X_8 + 0.0312X_9 + 0.0007X_{10} + 3.5510$	37	0.675**
2	$\hat{Y}_1 = 0.0124X_1 + 1.6132X_6 + 0.3246X_7 - 1.0251X_8 + 3.5270$	40	0.664**
3	$\hat{Y}_1 = 0.0142X_1 + 1.6692X_6 + 0.3964X_7 - 6.5993$	41	0.644**
4	$\hat{Y}_2 = 0.0132X_1 + 0.4538X_2 - 0.0373X_3 - 0.0057X_4 - 23.4859$	304	0.461**
5	$\hat{Y}_2 = 0.0131X_1 + 0.4892X_2 - 28.6376$	306	0.459**
6	$\hat{Y}_3 = 0.0017X_1 + 0.0844X_2 - 0.0118X_3 - 0.0278X_4 + 1.7755$	304	0.406**
7	$\hat{Y}_3 = 0.0017X_1 + 0.0801X_2 + 1.1086$	306	0.405**
8	$\hat{Y}_4 = 15.0584X_6 + 0.7658X_7 - 23.4890X_8 + 2.8080X_{11} + 226.9242$	40	0.784**
9	$\hat{Y}_4 = 14.1268X_6 - 25.0875X_8 + 3.2032X_{11} + 209.2801$	41	0.780**

[a] Key to X and Y values:

$\hat{Y}_1$ = Honey bee populations by blocks	X_4 = Vapor pressure deficit
$\hat{Y}_2$ = Honey bee populations by periods	X_5 = Stand
$\hat{Y}_3$ = Rate of honey bee visits to flowers by periods	X_6 = Elevation
	X_7 = Plant height
$\hat{Y}_4$ = Seed yield by blocks	X_8 = Soil pH
X_1 = Light intensity	X_9 = Available phosphorus
X_2 = Air temperature	X_{10} = Available potassium
X_3 = Relative humidity	X_{11} = Honey bee populations

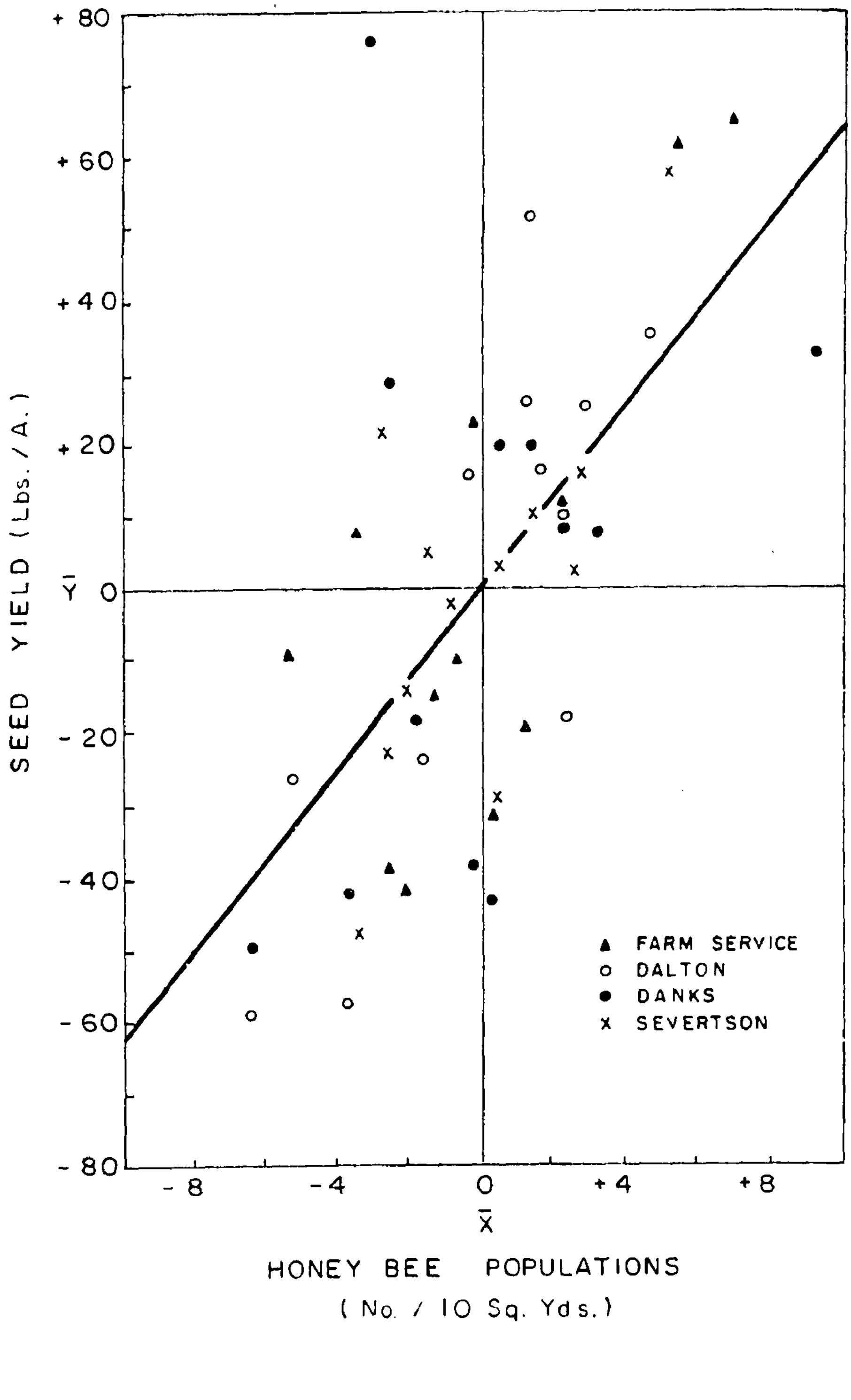
** Significant at 1 percent probability

Fig. 21. Average within-field regression of seed yield on honey bee populations, four fields. Ames, 1950.

$\bar{y}$ = 123 pounds per acre, mean seed yield

$\bar{x}$ = 15.8 bees per 10 square yards, mean honey bee population

$\hat{Y} = 6.2159X + 25.16$


+ 80
+ 60
+ 40
+ 20
Ȳ 0
- 20
- 40
- 60
- 80
SEED YIELD (Lbs. / A.)
- 8
- 4
0
+ 4
+ 8
X̄
HONEY BEE POPULATIONS
(No. / 10 Sq. Yds.)
▲ FARM SERVICE
○ DALTON
● DANKS
x SEVERTSON

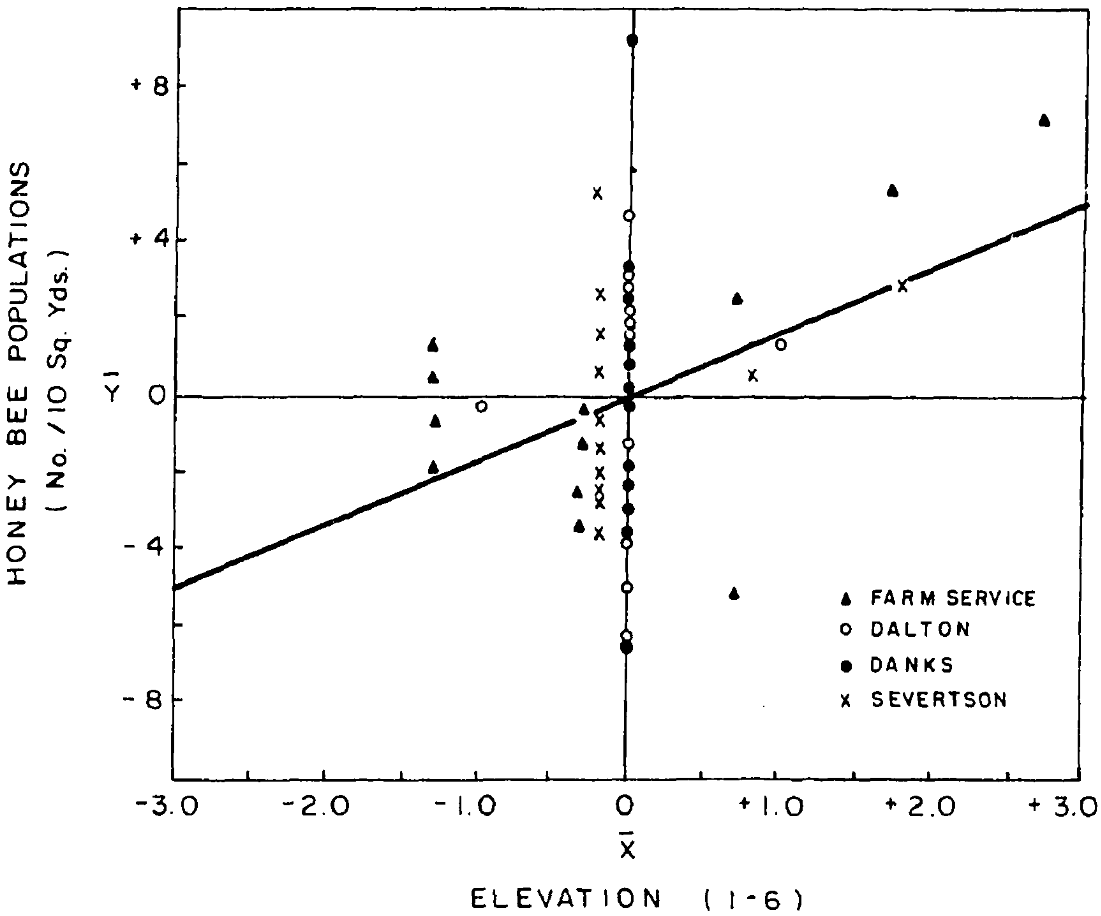


Fig. 22. Average within-field regression of honey bee populations on elevation, four fields. Ames, 1950.

$\bar{y}$ = 15.8 bees per 10 square yards, mean honey bee population

$\bar{x}$ = 2.4 mean elevation (1 is low; 6, high)

$\hat{Y}$ = 1.6709X + 11.76

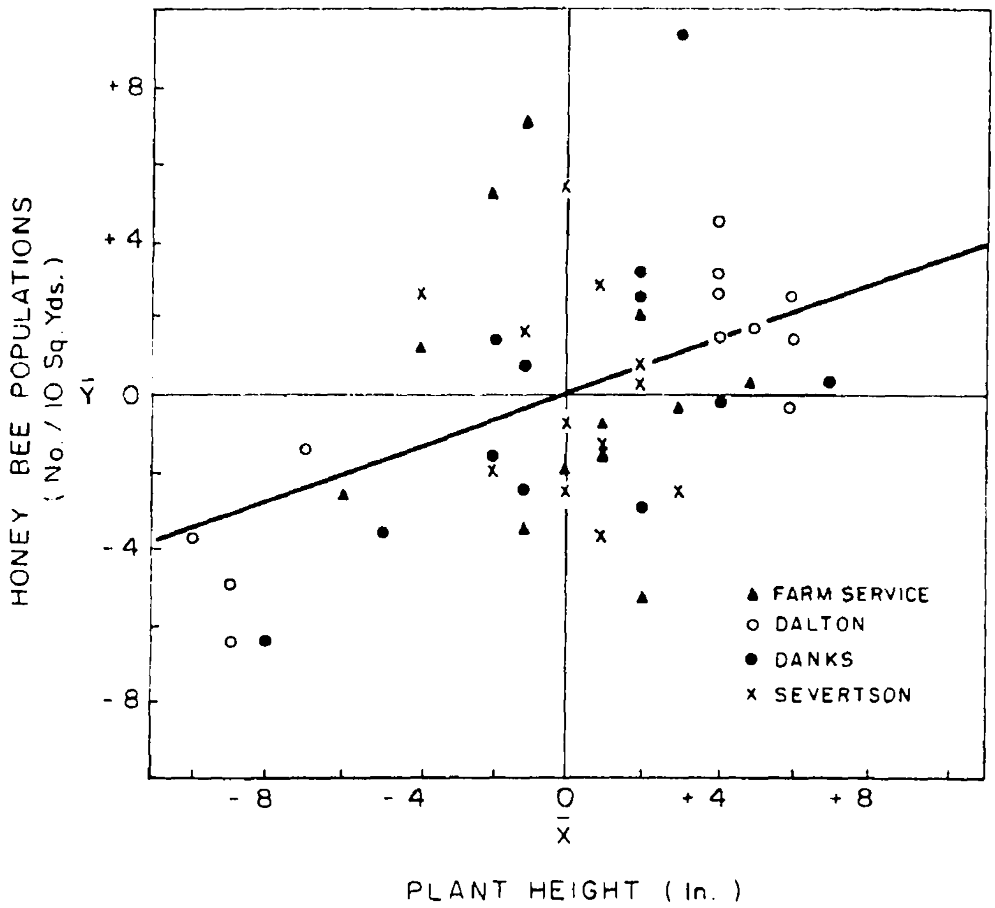


Fig. 23. Average within-field regression of honey bee populations on plant height, four fields. Ames, 1950.

$\bar{y}$ = 15.8 bees per 10 square yards, mean honey bee population

$\bar{x}$ = 32 inches, mean plant height

$\hat{Y} = 0.3664X + 4.18$

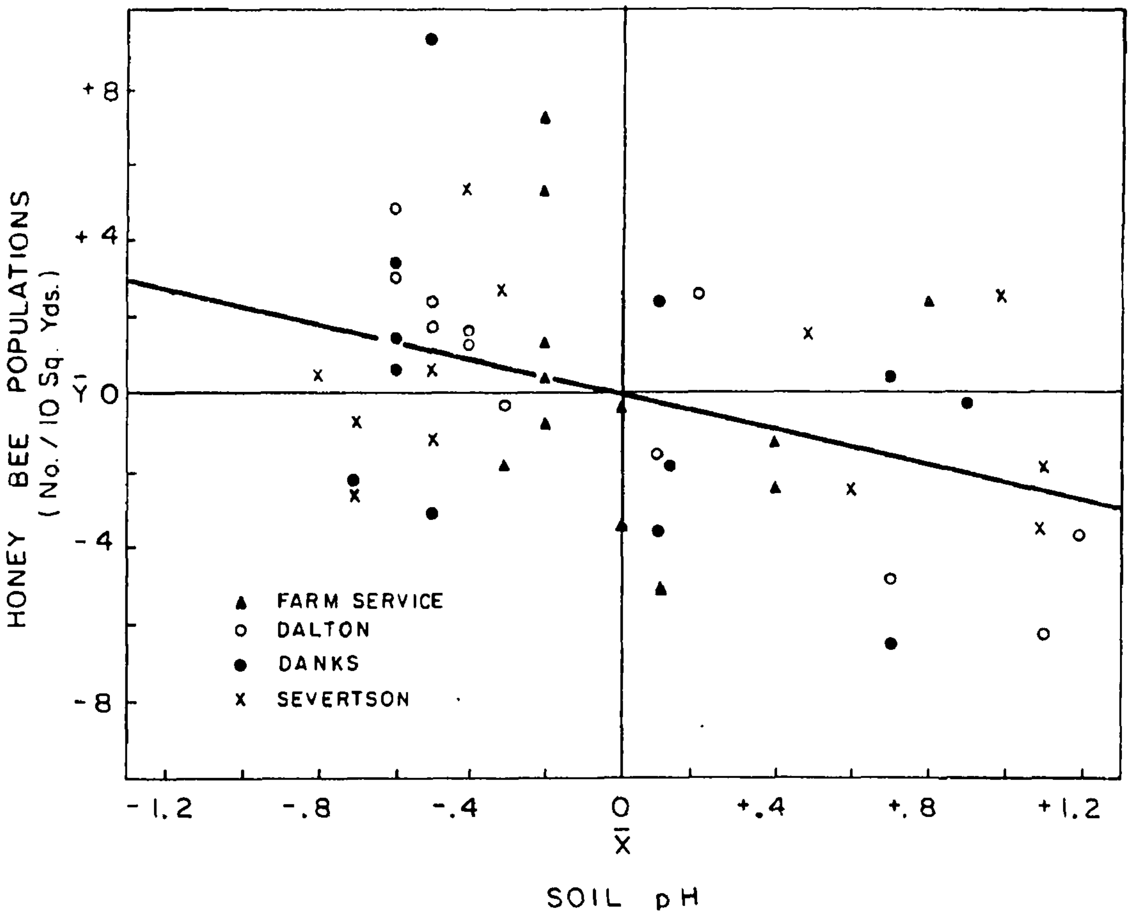


Fig. 24. Average within-field regression of honey bee populations on soil pH, four fields. Ames, 1950.

$\bar{y}$ = 15.8 bees per 10 square yards, mean honey bee population

$\bar{x}$ = 6.8 mean soil pH

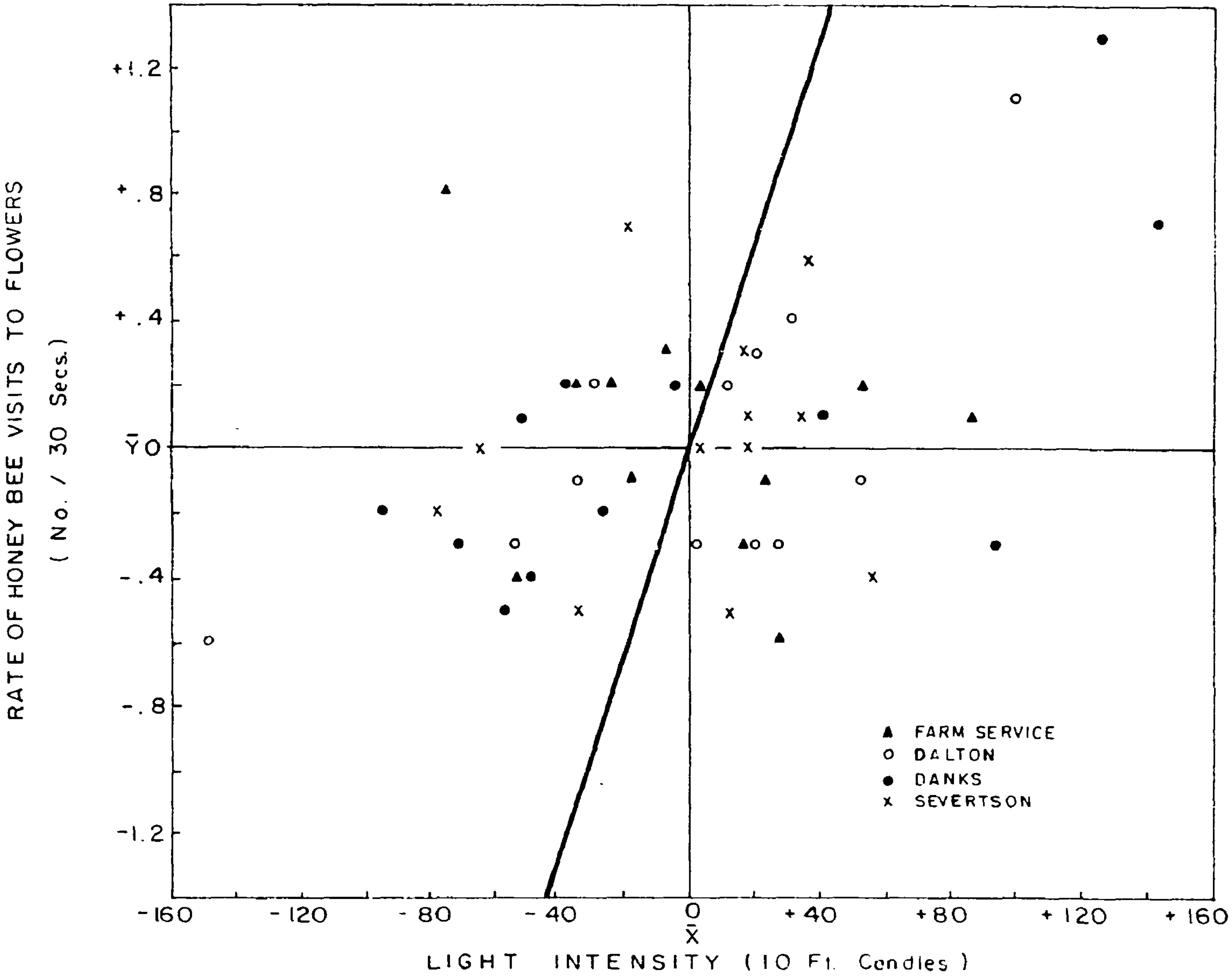
$\hat{Y}$ = -2.3163X + 31.63

Fig. 25. Average within-field regression of rate of honey bee visits to flowers on light intensity, four fields. Ames, 1950.

$\bar{y}$ = 8.2 per 30 seconds, mean rate of honey bee visits to flowers

$\bar{x}$ = 402, mean light intensity in 10 foot candles

$\hat{Y} = 0.0032X + 6.91$


RATE OF HONEY BEE VISITS TO FLOWERS
(No. / 30 Secs.)
+1.2
+.8
+.4
Ȳ 0
-.4
-.8
-1.2
-160
-120
-80
-40
0
X̄
+40
+80
+120
+160
LIGHT INTENSITY (10 Ft. Candles)
FARM SERVICE
DALTON
DANKS
SEVERTSON

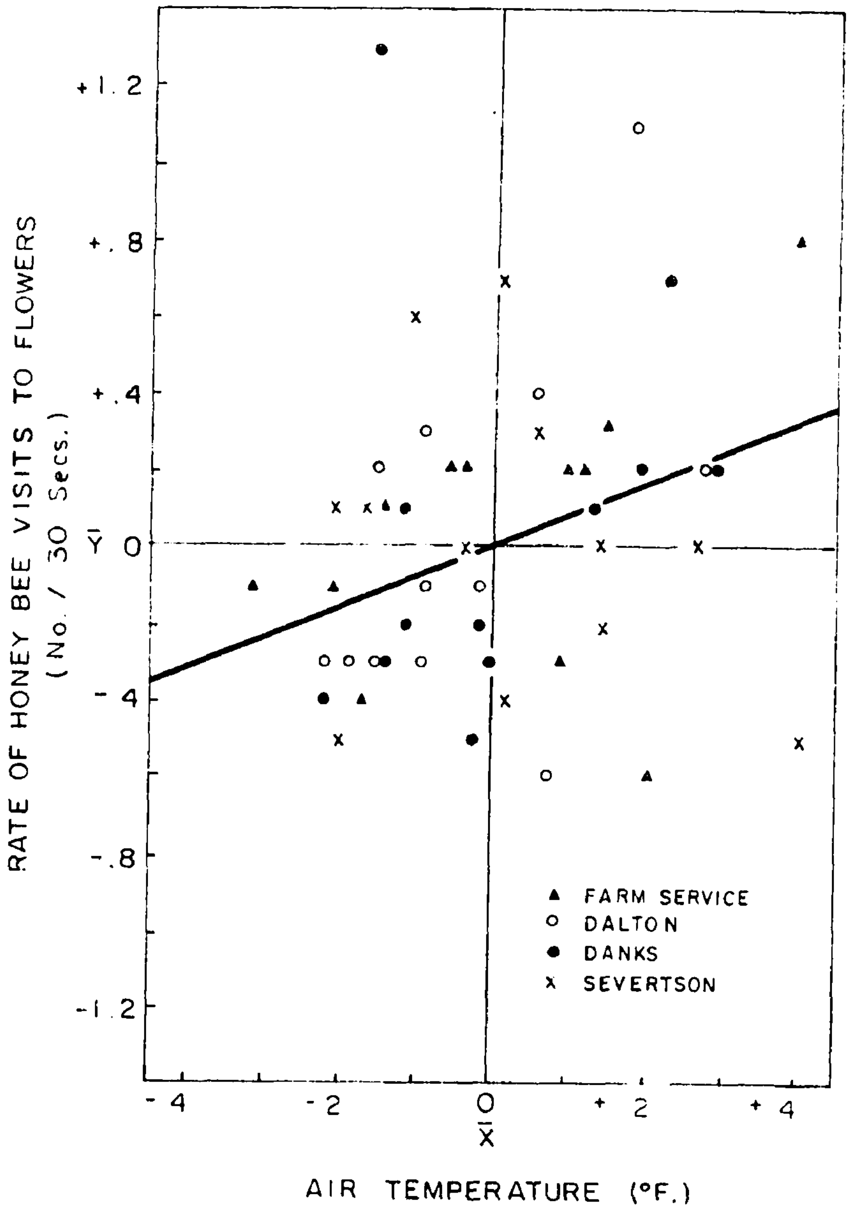


Fig. 26. Average within-field regression of rate of honey bee visits to flowers on air temperature, four fields. Ames, 1950.

$\bar{y}$ = 8.2 per 30 seconds, mean rate of honey bee visits to flowers

$\bar{x}$ = 80° F., mean air temperature

$\hat{Y}$ = 0.0758X + 2.14

Fig. 27. Average within-field regression of seed yield on elevation, four fields. Ames, 1950.

$\bar{y}$ = 123 pounds per acre, mean seed yield

$\bar{x}$ = 2.4 mean elevation (1 is low; 6, high)

$\hat{Y} = 20.7197X + 73.51$

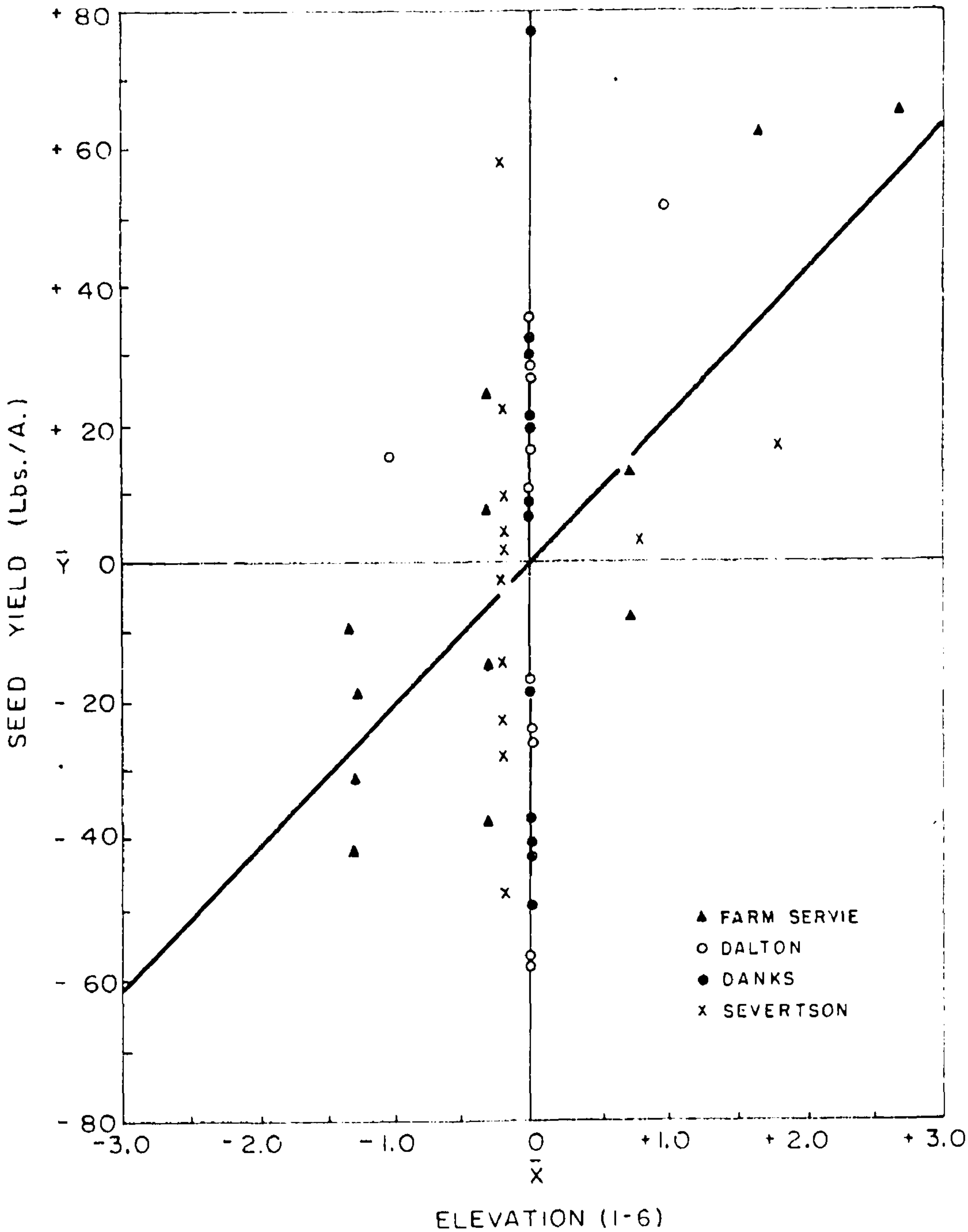

+ 80
+ 60
+ 40
+ 20
$\bar{Y}$ 0
- 20
- 40
- 60
- 80
SEED YIELD (Lbs./A.)
-3.0
- 2.0
- 1.0
0
$\bar{X}$
+1.0
+ 2.0
+ 3.0
ELEVATION (1-6)
▲ FARM SERVIE
o DALTON
● DANKS
x SEVERTSON

Fig. 28. Average within-field regression of seed yield on plant height, four fields. Ames, 1950.

$\bar{y}$ = 123 pounds per acre, mean seed yield

$\bar{x}$ = 32 inches, mean plant height

$\hat{Y} = 3.2742X + 19.48$

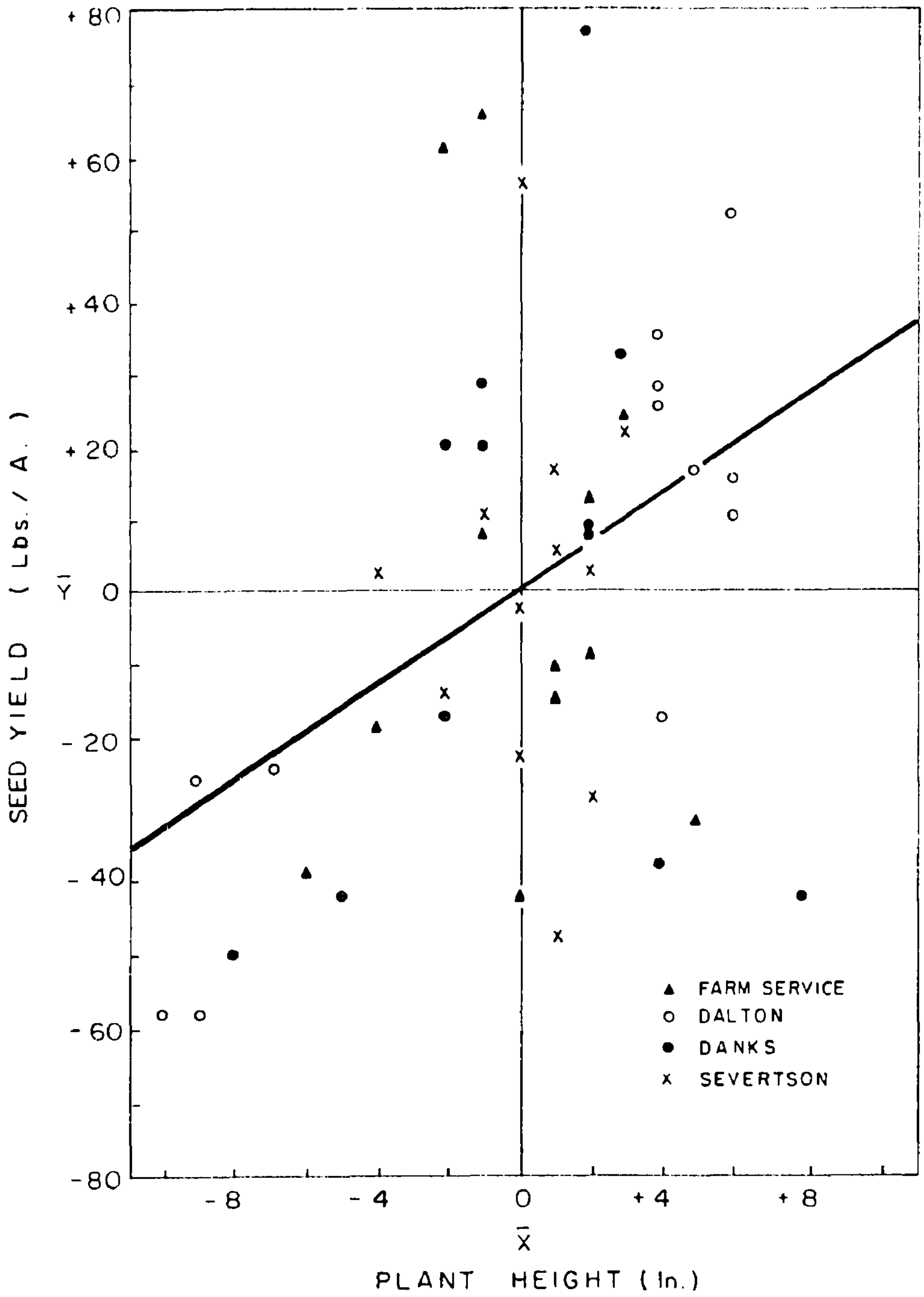
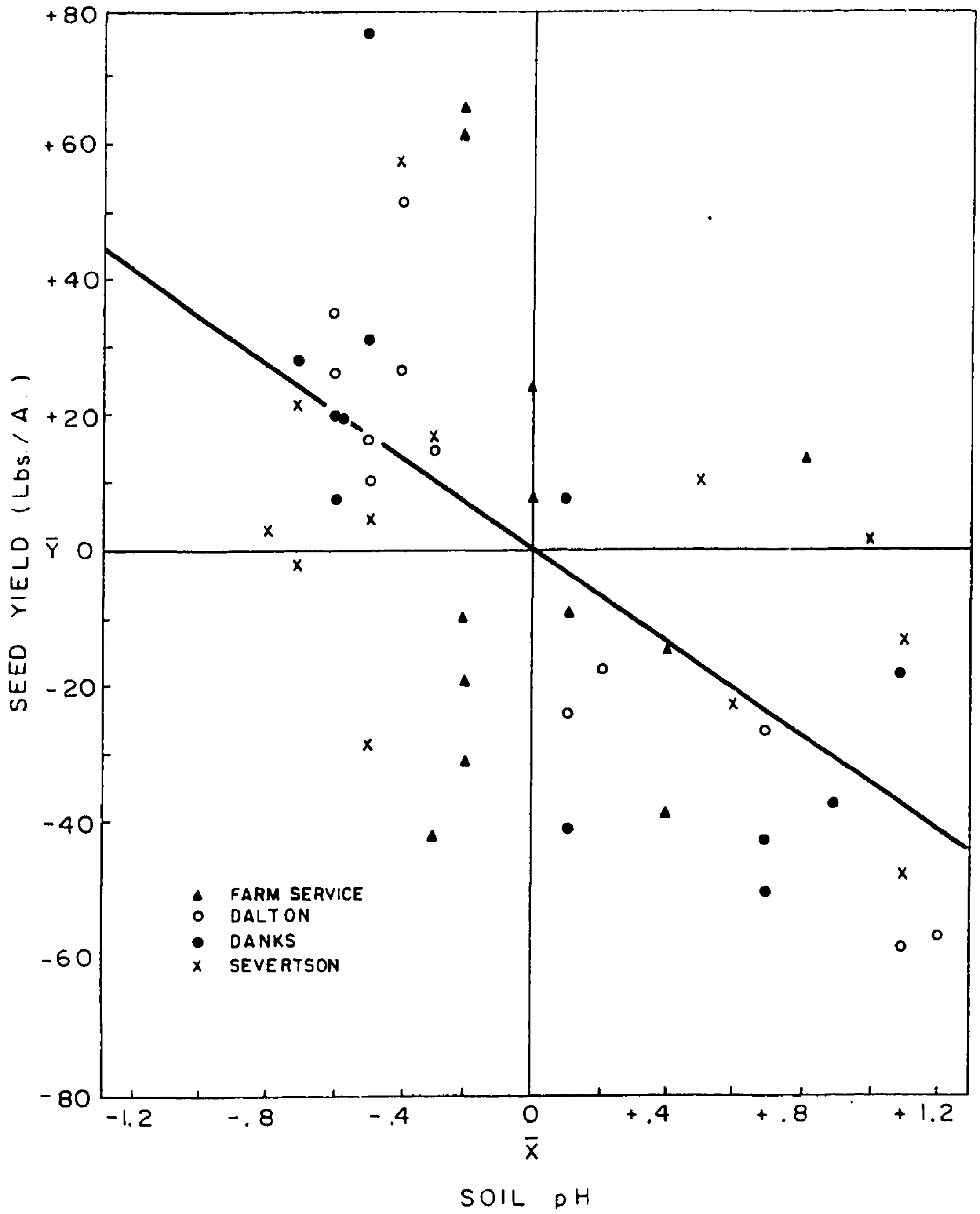

+80
+60
+40
+20
0
-20
-40
-60
-80
SEED YIELD (Lbs./A.)
Ȳ
-8
-4
0
+4
+8
X̄
PLANT HEIGHT (In.)
FARM SERVICE
DALTON
DANKS
SEVERTSON

Fig. 29. Average within-field regression of seed yield on soil pH, four fields. Ames, 1950.

$\bar{y}$ = 123 pounds per acre, mean seed yield

$\bar{x}$ = 6.8, mean pH

$\hat{Y} = -33.4198X + 351.88$



+80
+60
+40
+20
$\bar{Y}$ 0
-20
-40
-60
-80
SEED YIELD (Lbs./A.)
-1.2
-.8
-.4
0
+.4
+.8
+1.2
$\bar{X}$
SOIL pH
FARM SERVICE
DALTON
DANKS
SEVERTSON

of populations show. (Figures are averages for eight observations on each of the 10 plots per block.)

Field	Range in number of bees per 10 square yards
Farm Service (Table 4)	12.2 - 24.4
Dalton (Table 5)	5.2 - 16.4
Danks (Table 6)	11.1 - 26.8
Severtson (Table 7)	13.0 - 21.6

Bee populations and seed yield were found to be highly correlated ($r = 0.620$, Table 10), and Figure 21 shows the regression of seed yield on bee population. On the average as the mean number of bees per 10 square yards increased by one, the yield per acre increased by 6.216 pounds per acre. With few exceptions the data from all four fields conform to this trend of positive relationship between bee populations and seed yield.

The correlation coefficient for honey bee population with elevation ($r = 0.351$, Table 10) was statistically significant at the 5 percent level. Figure 22 shows a positive regression of honey bee populations on field elevation. The data indicate that as the average elevation increased by one the honey bee population increased 1.671 bees per 10 square yards (Table 12, Equation 16). This trend is evident mostly in the Farm Service field, which is the only field showing appreciable elevation differences.

Bee populations and plant heights showed a highly significant correlation ($r = 0.465$, Table 10). Figure 23 illustrates a positive regression of honey bee populations on plant height. The regression equation indicates that as the mean plant height increased 1 inch, bee populations increased 0.366 bees per 10 square yards (Table 12, Equation 17). This positive relationship between plant height and bee population appears to be negligible on the Farm Service and Severtson fields, as evidenced by the scatter of the points that represent those fields on the graph, but the fit appears to be better for the Danks and Dalton fields.

A highly significant negative correlation ($r = -0.426$, Table 10) was shown between bee populations and soil pH; the regression of bee populations on pH is shown graphically in Figure 24. On the average as the mean pH increased by one, the honey bee population decreased 2.3163 bees per 10 square yards (Table 12, Equation 18). The tendency toward a regression of bee populations on pH is most pronounced in the Danks and Dalton fields, with the Farm Service and Severtson fields apparently showing much less correlation between these two factors. The distribution of points on the graph indicate that the relationship between these two factors may not have been linear; there was a rapid decrease in bee populations when the soil pH was in the lower ranges, about 6.1 to 6.3.

Correlation coefficients for honey bee populations and various weather factors were first determined on the basis of seasonal block averages (Table 10). On this basis little or no relationship was found between honey bee populations and wind velocity, light intensity, air temperature, relative humidity, or vapor pressure deficit. However, when honey bee populations were correlated with weather factors on the basis of individual 2-day observation periods throughout the season (Table 11), highly significant positive correlations were obtained between the bee populations and light intensity ($r = 0.341$), air temperature ($r = 0.357$), and vapor pressure deficit ($r = 0.285$). Also a highly significant negative correlation was obtained for honey bee populations and relative humidity ($r = -0.202$).

Small positive correlations were shown between honey bee populations and light intensity, available phosphorus, and available potassium on the basis of seasonal averages (Table 10), but these correlations were not statistically significant.

Rate of honey bee visits to flowers. The analysis of variance indicates that the mean difference in the rate of honey bee visits to alfalfa flowers between Location I and Location II was highly significant (Table 8). The mean difference in rate of visitation was also significant between the two treatments (four colonies of bees moved in *vs.* no bees moved into the field). The block means for rate of honey bee visits to alfalfa flowers in Tables 4 through 7 show that there was a consistent tendency for bees to visit at a slower rate at the Dalton field than on the other three fields. It seems likely that the low rates of bee visitation in Dalton field were the main source of significant differences for both locations and treatments.

Light intensity and rate of bee visits to flowers were positively correlated, according to an analysis of block means for the season ($r = 0.438$, Table 10). Figure 25 shows a positive regression of the rate at which honey bees visited flowers on the light intensity. A poor fit of the data to the calculated regression line is shown in Figure 25. It seems probable that there was actually very little relationship between the rate of bee visits and light intensity and that the apparent regression may have been influenced unduly by several extreme values. The correlation of the rate honey bees visited flowers and light intensity was highly significant when the analysis was based on means for 2-day observation periods ($r = 0.273$, Table 11).

Rates of bee visitation showed a significant correlation to air temperature, based on seasonal block averages ($r = 0.292$, Table 10), and this correlation became highly significant when analyzed on the basis of 2-day observation periods ($r = 0.338$, Table 11). Figure 26 shows the regression of the rate of honey bee visitation on air temperature, based on seasonal averages. The average regression and the individual field data plotted on the graph show little effect of temperature on the rate bees visited flowers. This apparent correlation probably reflects the influence of a few extreme values and suggests a relationship that did not actually exist.

Correlations between rate of honey bee visits and wind, relative humidity, and vapor pressure deficit were not significant when the data were analyzed by block averages for the season (Table 10). However, the correlations were highly significant for rate of bee visits with air temperature ($r = 0.338$), vapor pressure deficit ($r = 0.263$), and relative humidity ($r = -0.186$), when the data were analyzed by 2-day observation periods (Table 11). There was no evidence of a correlation between wind and the rate of bee visits in analyses by seasonal means or by means of 2-day observation periods.

There was little or no apparent correlation between the rate of honey bee visits to alfalfa flowers and each of the following: stand, elevation, plant height, soil pH, available phosphorus, or available potassium.

Climatological factors. Mean differences in wind velocity for treatments were shown by analysis of variance of seasonal block averages to be highly significant, and the interaction between treatments and locations was significant at the 5 percent level (Table 8). Differences in average wind velocity were shown to be even more pronounced when the means for 2-day time periods were examined by analysis of variance. This analysis showed highly significant differences in the average wind velocity on fields and between periods. The interaction of periods with fields was also highly significant (Table 9).

Examination of the seasonal field means for wind velocity in Table 3 and the seasonal block means in Tables 4 through 7 shows that wind velocity was consistently lowest in the Dalton field. There was not a significant correlation between wind velocity and bee populations, rate of visitation, nor seed yield on the basis of seasonal block means; in analyses of the means for 2-day observation periods, wind likewise failed to show correlation with bee populations or rate of visits to flowers.

Significant mean differences in light intensity between treatments were indicated by the analysis of variance based on seasonal block means (Table 8). Analysis of variance of light intensity data calculated on block averages for 2-day observation periods showed a significant mean difference between periods and a significant interaction between periods and fields (Table 9). The summary of field means indicates that uniformly lower light intensities were recorded in the fields of Location I compared with Location II; these uniform differences in light readings probably obscured any significant variation for treatments (Table 3). Correlation coefficients for light with agronomic factors were generally low; the analyses showed the greatest correlation was a positive but non-significant correlation between stand and light intensity (r = 0.200, Table 10). The correlation between light and air temperature was significant at a probability of 1 percent in the analyses of data for 2-day observation periods (r = 0.155, Table 11).

There were no significant differences in average temperature, relative humidity, or vapor pressure deficit associated with locations, treatments, or the interaction between treatments and locations in a study of block means for the season (Table 8).

The analyses of variance of the following data, based on means of 2-day observation periods, showed highly significant mean differences between periods: temperature, relative humidity, and vapor pressure deficit. Analysis of variance of relative humidity and vapor pressure deficit data showed a significant interaction between periods and fields (Table 9). The correlations of air temperature with relative humidity (r = 0.501, Table 11) and with vapor pressure deficit (r = 0.764) were highly significant. Temperature was, of course, correlated negatively with relative humidity and positively with vapor pressure deficit; relative humidity and vapor pressure deficit logically showed a highly significant negative correlation (r = -0.906).

Agronomic factors. Analysis of variance of stand data, based on block means, shows a significant interaction between treatments and locations (Table 8). Mean differences in stand between locations and between treatments were not significant. The main source of variation in stand was the Farm Service field, which had the most plants per square yard (Tables 3 through 7). The Severtson and Dalton fields had more uniform stands than the Farm Service and Danks fields, and the Danks field had the thinnest stand.

Correlation coefficients in Table 10 show a highly significant correlation between stand and plant height ($r = 0.580$) and for stand with available potassium ($r = 0.375$). The correlation of stand with elevation ($r = -0.210$) was negative and it approached significance at the 5 percent level. Correlations were not significant between stand and each of the following: seed yields, honey bee populations, rate of bee visits to alfalfa flowers, light intensity, elevations, soil pH, or available phosphorus.

Mean difference in elevation between locations and between treatments was statistically significant, and there was a significant interaction between treatments and location (Table 8). Means presented in Tables 3 through 7 show that the Farm Service field was responsible for nearly all of the variation associated with elevation. Figures 13, 15, 16, and 17 also show that there was considerable irregularity in the topography of the Farm Service field, but that there were only minor differences in the other three fields.

There was a positive but nonsignificant tendency for phosphorus and potassium to be associated with differences in elevation and a negative but insignificant trend toward correlation of elevation with stand. There did not appear to be any tendency for differences in plant height or soil pH to be associated with differences in elevation (Table 10).

Figure 27 shows the regression of seed yield on elevation. The Danks, Dalton, and Severtson fields had only small differences in elevation, as is indicated by the points representing these fields on the graph. The Farm Service field shows most of the positive regression of seed yield on elevation. The regression equation indicates that an increase of 20.72 pounds per acre might have been expected with each unit increase in elevation (each unit of elevation was equal to approximately 8 feet).

Analysis of variance of plant height data showed a significant mean difference between locations and a significant interaction between treatments and locations, but differences between treatments were not significant (Table 8). Plants in Location I had a greater average height than those in Location II, but the taller plants in the Farm Service field appeared to be the main source of variation in plant heights for locations and for fields (Tables 3 through 7).

There was a highly significant correlation between plant height and seed yields ($r = 0.414$), which indicated that 17.15 percent of the variation in seed yields was associated with plant height. These data indicate that within the limits of plant height found in these fields, the taller the plants the greater the seed yields. A comparison of plant height with seed yields for the four fields in Table 3 might appear to contradict this conclusion, because the tallest plants are associated with the highest yield in one field (Farm Service), while the lowest height of the four fields (Danks) gave the second highest yield. However, examination of block totals for plant heights and seed yields on individual fields (Tables 4 through 7) shows that within fields there is a tendency for high yields and tall plants to be associated.

Figure 28 shows a positive regression of seed yield on plant height. On the basis of these data an increase of 3.274 pounds per acre might be expected with each inch increase in plant height under these particular conditions (Table 12, Equation 5). This regression is most apparent in the Dalton field, the other three fields showing little if any apparent effect of height on yield.

Plant height was shown to have a highly significant negative correlation with pH ($r = -0.465$, Table 10). The field means in Table 3 show that the lowest average pH, 6.6, was associated with the tallest plants, 37 inches at Farm Service. The block averages for plant height and soil pH in Table 4 indicate there was a more uniform plant height and favorable pH in Farm Service than in the other three fields. Plant heights at the Dalton field were more uneven than those in the other three fields. The correlation coefficient for plant height and available potassium was significant at a probability of 5 percent ($r = 0.371$), but the correlation coefficient for plant height and available phosphorus only approached significance ($r = 0.280$).

Only small differences in pH existed among the four experimental fields, but the range of variation was appreciable within individual fields (Tables 3 through 7). Comparison of seasonal block means by analysis of variance indicates that none of the differences in pH were significant (Table 8), but the small differences that existed were closely correlated with differences in seed yields ($r = -0.613$, Table 10). Little relationship between soil pH and available phosphorus, available potassium, rate of honey bee visits to flowers, light intensity, or elevation was shown by the statistical analysis.

Soil tests revealed considerable variation in the amounts of available phosphorus between fields and within some fields. The analysis of variance showed a significant mean difference between locations and between treatments. There was a significant interaction between treatments and locations (Table 8).

Coincidentally the two fields where bees were not brought in for the experiment (Farm Service and Danks) had more available phosphorus per acre than the two fields where the bees were brought in, as shown in Tables 3 through 7; the amount of available phosphorus at the Farm Service field was appreciably higher than that of the other three fields. Available phosphorus was not shown to be significantly correlated with any of the variables studied, although the correlations with honey bee populations, elevation, and plant height approached significance at the 5 percent level (Table 8).

Analysis of variance of available potassium data showed a significant mean difference between treatments (fields with bees moved in *vs.* fields without bees moved in) as presented in Table 8. The means in Table 3 indicate that soil from the Farm Service field and from the Danks field contained more available potassium than soil from either of the other two fields.

Check fields, where bees were not moved into the fields (Farm Service and Danks), yielded more seed (168 and 140 pounds per acre, respectively) than the two fields where four colonies of bees per acre were moved in (Dalton field, 94 pounds per acre, and Severtson, 90 pounds per acre). However, there actually were more bees present on the "check" fields than on the others (Tables 3 through 7). Average numbers of honey bees per 10 square yards in the various fields were: Farm Service, 17.4; Dalton, 11.6; Danks, 17.5; and Severtson, 16.5.

Analysis of variance of seed yield data showed a significant mean difference between treatments (fields where bees were not moved in *vs.* fields into which four colonies of bees were moved) as indicated in Table 8. The means in Table 3 show that the higher yields were in the "no bee" fields and not in the fields where the bees were moved in, but this does not indicate that moving bees into these fields failed to increase yields. Actually there was not a "no bee" treatment, as all fields had honey bees working in them and the fields which had the greatest bee populations also produced the largest seed yields. The analysis of variance indicated that mean differences in seed yields between locations were not significant.

The highly significant correlations of seed yield with bee populations, elevation, plant height, and soil pH and the lack of correlation with rate of honey bee visits to flowers, wind velocity, light, stand, available phosphorus, and available potassium have already been discussed.

Multiple correlations

Multiple regression equations and correlation coefficients that were calculated for several combinations of variables studied in 1950 are presented in Table 13. The results presented were obtained by first calculating the multiple correlations of variables which other analyses had shown were related. Those variables shown not to be related were eliminated from the final analysis. All the regression equations and multiple correlation coefficients that were obtained by these analyses are shown in Table 13.

Honey bee populations. Three multiple correlation analyses were made on the basis of seasonal block means in a study of the relationship of several factors to honey bee populations. Results of these analyses are shown in Equations 1, 2, and 3 (Table 13).

The multiple correlation value shown in Equation 1 ($R = 0.675$, Table 13) indicates that 46 percent of the variation in honey bee populations was associated with plant height, stand, elevation, soil pH, available phosphorus, available potassium, and light intensity. Stand, soil pH, available phosphorus, and available potassium appeared to contribute little to the variations in honey bee populations, as indicated by the small change in the multiple correlation coefficient when they were left out of the analysis ($R = 0.664$, Equation 2). In the final analysis obtained the multiple correlation coefficient showed that approximately 41 percent of the variability of honey bee populations was associated with plant height, elevation, and light intensity ($R = 0.644$, Equation 3).

Two multiple correlation analyses of factors associated with honey bee populations were made on a basis of 2-day observation periods instead of block means (Table 13, Equations 4 and 5). These data suggest that approximately 21 percent of the variations in honey bee populations were accounted for by the combined effects of vapor pressure deficit, relative humidity, light intensity, and air temperature. The influence of light intensity and air temperature only (Equation 5) is about the same as the total influence of the four variables listed in Equation 4, i.e., about 21 percent.

Rate of honey bee visits to flowers. About 16 percent of the variation in the rate honey bees visit alfalfa flowers was associated with the combined influence of vapor pressure deficit, relative humidity, light intensity, and air temperature ($R = 0.406$, Table 13, Equation 6). Equation 7 shows that the net effect was altered only slightly when vapor pressure deficit and relative humidity were dropped from the analysis, because the percentage of variation in bee activity associated with light intensity and air temperature only was also approximately 16.

Seed yield. Approximately 62 percent of the variability in seed yields was linearly associated with plant height, elevation, soil pH, and honey bee populations ($R = 0.784$, Table 13, Equation 8). When plant height was not included in the analysis the correlation coefficient was changed very little ($R = 0.780$, Equation 9).

Discussion of 1950 experiments

Honey bees were present in all four experimental fields, even though colonies were not moved into two of them. This anomalous situation was apparently brought about by three principal factors: (1) there were enough honey bee colonies within flight range of all four fields to supply the number of bees that were observed, as shown in Table 14; (2) there were many acres of competing crops near the experimental fields, as is indicated in Table 14; and (3) certain conditions shown to be associated with higher bee populations were more favorable on control fields than on fields where colonies of bees were supplied.

Table 14. Approximate number of honey bee colonies and acres of forage legumes within a 2-mile radius of each of four fields studied. Ames, 1950.

	Farm Service (check)	Dalton (four colonies bees per acre)	Danks (check)	Severtson (four colonies bees per acre)
Number of honey bee colonies	232	100	180	160
Acres of forage legumes				
Sweetclover	96	6	125	186
Red clover	166	144	717	550
Alfalfa	22	22	90	77

Seed yields were more closely correlated with honey bee populations than with any other factor considered in these experiments. These results offer substantial evidence that seed yields could be increased if the number of honey bees present were increased.

Weather factors were the only variables affecting bee populations on which recurrent observations were taken throughout the season. Bee populations could, therefore, be correlated both with weather factors for individual periods and with the seasonal means of these same factors.

The differences in these results were striking. Averaging the weather factors over the entire season so obscured day-to-day and week-to-week variations that any relationship to the ups and downs of bee populations was almost completely lost. Not a single correlation of bee population with seasonal averages of weather variables was significant. In contrast, correlations of honey bee populations with the weather for corresponding individual 2-day periods was highly significant for light intensity, air temperature, vapor pressure deficit, and relative humidity, the latter being strongly negative. The high correlation with bee populations for individual periods constitutes strong evidence that increased light intensity, warm temperatures, and decreased humidity were all conducive to greater bee activity in the field over the ranges these variables were encountered in this experiment.

These results, which indicate that bee activities increased with light intensity, warm temperatures, and air dryness, are those that might be expected within the ranges of variation found in these studies. The interpretation of the effects on honey bees as pollinators of alfalfa is more difficult, however, than the mere conclusion that honey bee activities were increased. There appeared to be little relationship between the rate of bee visits to alfalfa flowers and seed yields, and since the honey bees observed tripped few flowers under all conditions, it seems reasonable to conclude that other factors, such as competition, limited the value of honey bees as pollinators of alfalfa more than weather factors.

Light readings were much the same on the Farm Service, Danks, and

Dalton fields, but were considerable higher on the Severtson field. No physical explanation for this relationship was apparent, and it is possible this was just a chance occurrence. It seems doubtful that this difference in light was responsible for differences in seed yields, since there was little correlation between light and seed yield or rate of visits and yield. The Danks and Dalton fields apparently would have shown a positive regression of rate of bee visitation on light, but such an effect would have been attributed primarily to three or four single observations of high light intensity and high rate of visits to flowers. The Farm Service and Severtson fields showed little effect of light intensity on rate of bee visitation.

Wind velocities appeared to have no appreciable relationship to honey bee populations or the rate bees visited alfalfa flowers.

The highly significant correlation between bee populations and plant height plus the positive regression of bee populations on plant height indicate that plant height had a definite connection with bee populations in this study. However, there was little evidence to show whether or not this relationship was causative. It seems possible that the same factors which governed plant height might also have governed nectar secretion, number of flowers, or some other factor of attractiveness in the plant and thus have affected bee populations. There was evidence that available potassium and soil pH, which are known to influence plant growth, were definitely correlated with plant height, and that available phosphorus showed strong tendencies toward correlation with plant height.

Several possible explanations for the inefficiency of honey bees in pollinating alfalfa under conditions of this study seem tenable. Competition for bees by red clover and other surrounding crops certainly limited the effectiveness of the bees in alfalfa. Pollen traps[1] on colonies at Dalton and Severtson fields indicated that large amounts of red clover pollen were being collected, and farmers who harvested red clover seed a few hundred feet from the experimental fields reported unusually high yields. Visual observation of bee flights disclosed that the bees were foraging outside the experimental fields. If the work of Reinhardt (1952) is sound, management of the bees in these experiments was probably not the best. The bees were left in the same fields many weeks, which may have resulted in a field force of experienced bees that could collect nectar from alfalfa flowers without tripping them. The average percentage of tripping observed during this study was 0.25 percent (Table 15). Hobbs (1952) listed tripping percentages for other states that may be used for comparison: Ohio, 2.7; Nebraska, 0.6 and 0.3; Wyoming, 1.7; Utah, 0.5 to 2.0; and Canada, 0.7. The low percentage of flowers visited that were tripped by bees may indicate that experience, availability of other sources of pollen, and/or perhaps some other influences limited the effectiveness of honey bees in pollinating alfalfa in these investigations.

No definite connection is obvious between the slow rate bees visited flowers at the Dalton field and the other factors considered. In

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[1] The pollen traps were used by R. J. Walstrom in a separate study of pollen collection by honey bees.

Table 15. Number of alfalfa flowers visited and tripped by honey bees on four fields. Ames, 1950.

Field	Number of flowers visited	Number of flowers tripped	Percentage of flowers tripped
Farm Service	4,183	17	0.41
Dalton	3,926	10	0.25
Danks	4,757	5	0.10
Severtson	4,568	12	0.26
Total	17,434	44	0.25

1951 bees visited fewer red clover flowers per minute than alfalfa flowers. It was concluded that difficulties in obtaining nectar from clover might have influenced this slower rate of visitation. Difficulty in obtaining nectar could possibly have affected the rate of bee visits at the Dalton field also because this field had poor soil, was extremely dry during the growing season and, in general, had unfavorable plant conditions.

The significant correlation of stand with plant height probably reflected the better soil conditions of the Farm Service and Danks fields compared to Dalton and Severtson. The trend toward a negative correlation between stand and elevation was most likely associated with differences observed at Farm Service, where dense alfalfa growth was observed in the lower, moist areas of the field and where stands were definitely thinner on the elevated half. The quantity of available potassium present on the Farm Service field seemed to be correlated with better stands. The fact that stands and seed yields were not correlated in this study probably does not mean that stand and yield are not related, but perhaps indicates that stands were probably not as important in limiting seed production as some other factors in this experiment.

Seed growers have expressed the opinion that their best seed yields are frequently obtained on knolls or high ground. Some evidence to support this opinion was obtained, based mostly on data collected from the Farm Service field. These data indicate that an increase of 20 pounds of seed per acre might have been expected with an increase of one unit in elevation. (Based on elevation differences at Farm Service, one unit equaled approximately 8 feet.) Explanations for this association between elevation and seed yield were not completely clarified by evidence obtained in these studies, but there was a tendency toward increased amounts of soil phosphorus and potassium in higher elevations. Soil pH could possibly have been more favorable at higher elevations because of better drainage, and there was a highly significant positive correlation between honey bee populations and elevation. The relationship of higher bee populations to higher elevations could be purely physical in the sense that these higher areas were more accessible, or plants on high ground might have been relatively more attractive to bees. However, definite evidence to support these theories was not obtained.

It seemed unusual to find a highly significant negative correlation between soil pH and plant height, indicating that the higher the pH (more alkaline) the lower the plant height, because lime is often used to improve growth of alfalfa in the Midwest. However, the data indicate that this negative correlation probably resulted from several instances where high pH values were associated with decreased plant height. Burson (1954) suggested that pH's in the range of 6.5 to 7.0 are favorable for alfalfa plant growth and up to 7.3 might be expected to increase seed yields, but that pH's beyond 7.3 might reduce plant heights and seed yields because of the effect of pH on the availability of potassium and phosphorus. Hanway (1954) pointed out that glacial soils in Iowa sometimes have great pH differences in the same field, and called attention to the decreased availability of phosphorus at higher pH's. Another source of great variations in pH within fields, suggested by Hanway, was the bands of lime which might be present along water lines where bodies of water once stood for long periods and where shells of various forms of fauna were deposited. He speculated that certain correlations observed, such as the negative relationship between pH and bee populations and the positive correlation between plant height and seed yield, were probably not direct relationships but indirect effects of pH on availability of soil nutrients. The relationship of pH to availability of several elements in the soil is shown graphically in a diagram adapted from Truog by Thompson (1952) and reproduced in the Appendix (Figure 34).

1951 Experiments

Studies in 1951 included observations on both first and second crops of alfalfa and red clover. The first and second crops of alfalfa were divided into four insecticide treatments and four replications, but only three insecticide treatments and four replications were included in the red clover studies due to a loss of blocks caused by excess moisture. Six square-yard plots were randomly located in each block, and these plots were used for estimating bee populations and obtaining other data where such sampling units were required. The terms "blocks" and "plots" are used to identify the respective experimental units explained in the methods section.

Nectar and pollen data taken on second crops of alfalfa and red clover were compared only with honey bee population data taken within 1/2 hour of the same time. This was done to eliminate distortion of data by factors which might be associated with differences in time. As a result of this restriction some data were not used, and those included were obtained during five 2-day observation periods. Most other results of second crop alfalfa and red clover were based on eight 2-day observation periods.

Only two 2-day observation periods are included in first crop results for both alfalfa and red clover. The kinds of data recorded in a 2-day observation period have been explained in the methods section.

<u>First crop alfalfa</u>

A summary of the means of all variables considered on first crop alfalfa is given in Table 16, and more detailed data are contained in Tables 17 through 20. The analyses of variance are given in Table 21.

<u>Insect pollinators</u>. Wild bees were not found in the square-yard plots on first crop alfalfa, as shown in Tables 16 and 17. However, these values for wild bee populations do not represent a completely

Table 16. Summary of means of variables considered in study of first crop alfalfa seed production. Ames, 1951.

Factor studied	Mean for treatment: Check	Meth-oxy-chlor	Aldrin, DDT	Toxa-phene, DDT	Average of all treat-ments
Insect pollinators (no./6 sq. yds.)					
Wild bees	0.00	0.00	0.00	0.00	0.00
Cantharids	0.00	0.00	0.00	0.00	0.00
Honey bees	5.0	4.6	6.0	5.4	5.2
Honey bee activity					
No. flowers visited/30 secs.	9.5	8.9	8.8	9.3	9.1
No. flowers tripped by honey bees[a]	4	3	1	4	12[b]
Injurious insects (no./sweep).					
Lygus sp.	3.1	1.8	0.8	0.4	1.5
Leafhoppers	0.6	0.1	0.0	0.0	0.2
Alfalfa plant bugs	0.09	0.00	0.00	0.00	0.02
Rapid plant bugs	0.03	0.00	0.00	0.00	0.01
Grasshoppers	0.09	0.00	0.00	0.00	0.02
Climatological factors					
Wind velocity (mph)	4.4	4.4	5.1	5.0	4.7
Light (10 ft. candles)	153	178	259	292	220
Air temperature (° F.)	72.8	73.4	73.1	72.8	73.0
Relative humidity	65.0	65.1	66.4	66.2	65.7
Vapor pressure deficit	7.6	7.8	7.4	7.5	7.6
Atmometer reading (cc./hr.)	1.7	1.7	1.7	1.7	1.7
Agronomic factors					
Stand (1-4)	2.5	3.5	2.8	3.2	3.0
Elevation (1-6)	3.0	3.0	3.2	3.0	3.0
Plant height (in.)	23	22	23	22	23
Plant P (%)	0.25	0.22	0.24	0.23	0.23
Plant K (%)	1.79	1.68	1.78	1.98	1.81
Soil pH	7.1	7.4	7.2	6.9	7.1
Available P (lbs./A.)	5.0	3.4	4.9	3.6	4.2
Available K (lbs./A.)	180	174	174	205	183
Seed yield (lbs./A.)	26	31	51	58	41

[a] Totals, not averages
[b] Total flowers tripped of 1,077 visited, or 1.11 percent

Table 17. Means of insect pollinators and honey bee activity by replications and treatments, first crop alfalfa. Ames, 1951.

Treatment	Replication	No. insect pollinators (per 6 sq. yds.) Wild bees	Can-tharids	Honey bees	No. flowers visited by honey bees (per 30 secs.)	No. flowers tripped by honey bees[a]
Check	I	0.00	0.00	4.0	11.5	1
	II	0.00	0.00	5.0	8.6	1
	III	0.00	0.00	7.5	8.6	2
	IV	0.00	0.00	3.5	9.2	0
Average		0.00	0.00	5.0	9.5	4
Methoxychlor	I	0.00	0.00	4.0	9.5	0
	II	0.00	0.00	5.5	7.4	2
	III	0.00	0.00	4.0	10.2	1
	IV	0.00	0.00	5.0	8.5	0
Average		0.00	0.00	4.6	8.9	3
Aldrin, DDT	I	0.00	0.00	3.0	8.5	0
	II	0.00	0.00	4.5	8.8	1
	III	0.00	0.00	10.0	10.2	0
	IV	0.00	0.00	6.5	7.6	0
Average		0.00	0.00	6.0	8.8	1
Toxaphene, DDT	I	0.00	0.00	4.5	10.4	0
	II	0.00	0.00	5.5	8.5	2
	III	0.00	0.00	6.0	8.2	2
	IV	0.00	0.00	5.5	10.2	0
Average		0.00	0.00	5.4	9.3	4
Average for treatments		0.00	0.00	5.2	9.1	12[b]

[a] Totals, not averages

[b] Total flowers tripped of 1,077 visited, or 1.11 percent

Table 18. Means of relative numbers of injurious insects by replications and treatments, first crop alfalfa. Ames, 1951.

Treatment	Replication	Injurious insects (average number per sweep)				
		Lygus sp.	Leaf-hoppers	Alfalfa plant bugs	Rapid plant bugs	Grass-hoppers
Check	I	1.5	0.5	0.00	0.00	0.12
	II	2.0	1.0	0.00	0.00	0.12
	III	2.5	0.5	0.25	0.00	0.12
	IV	6.5	0.5	0.12	0.12	0.00
Average		3.1	0.6	0.09	0.03	0.09
Methoxychlor	I	1.5	0.5	0.00	0.00	0.00
	II	2.0	0.0	0.00	0.00	0.00
	III	0.5	0.0	0.00	0.00	0.00
	IV	3.0	0.0	0.00	0.00	0.00
Average		1.8	0.1	0.00	0.00	0.00
Aldrin, DDT	I	3.0	0.0	0.00	0.00	0.00
	II	0.0	0.0	0.00	0.00	0.00
	III	0.0	0.0	0.00	0.00	0.00
	IV	0.0	0.0	0.00	0.00	0.00
Average		0.8	0.0	0.00	0.00	0.00
Toxaphene, DDT	I	0.5	0.0	0.00	0.00	0.00
	II	1.0	0.0	0.00	0.00	0.00
	III	0.0	0.0	0.00	0.00	0.00
	IV	0.0	0.0	0.00	0.00	0.00
Average		0.4	0.0	0.00	0.00	0.00
Average for treatments		1.5	0.2	0.02	0.01	0.02

Table 19. Means of climatological factors by replications and treatments, first crop alfalfa. Ames, 1951.

Treatment	Replication	Climatological factors					
		Wind velocity (mph)	Light (10 ft. candles)	Air temperature (° F.)	Relative humidity	Vapor pressure deficit	Atmometer reading (cc./hr.)
Check	I	1.8	200	73.0	63.0	8.0	1.9
	II	5.4	93	69.5	70.5	6.0	1.5
	III	5.8	74	73.0	65.5	7.5	1.3
	IV	4.4	248	75.5	61.0	9.0	2.1
Average		4.4	153	72.8	65.0	7.6	1.7
Methoxychlor	I	1.8	198	73.0	63.0	8.0	1.9
	II	5.0	108	71.0	69.5	6.5	1.5
	III	6.6	200	73.5	67.0	7.0	1.3
	IV	4.0	204	76.0	61.0	9.5	2.1
Average		4.4	178	73.4	65.1	7.8	1.7
Aldrin, DDT	I	3.7	263	72.5	72.0	6.5	1.9
	II	5.1	230	70.0	69.5	6.0	1.5
	III	6.4	305	74.5	63.0	8.0	1.3
	IV	5.2	239	75.5	61.0	9.0	2.1
Average		5.1	259	73.1	66.4	7.4	1.7
Toxaphene, DDT	I	3.7	239	72.5	72.0	6.5	1.9
	II	6.2	136	68.5	70.5	5.5	1.5
	III	6.1	494	74.0	61.5	8.5	1.3
	IV	4.2	298	76.0	61.0	9.5	2.1
Average		5.0	292	72.8	66.2	7.5	1.7
Average for treatments		4.7	220	73.0	65.7	7.6	1.7

Table 20. Means of agronomic factors by replications and treatments, first crop alfalfa. Ames, 1951.

Treatment	Replication	Agronomic factors								
				Plant			Soil			
		Stand (1-4)	Eleva-tion (1-6)	Height (in.)	P (%)	K (%)	pH	Avail-able P (lbs./A.)	Avail-able K (lbs./A.)	Seed yield (lbs./A.)
Check	I	2	4	24	0.24	1.83	6.8	3.0	136	30
	II	3	2	26	0.26	1.66	7.3	4.0	164	30
	III	1	2	23	0.22	1.50	7.5	1.0	160	40
	IV	4	4	20	0.28	2.16	6.8	12.0	260	2
Average		2.5	3.0	23	0.25	1.79	7.1	5.0	180	26
Methoxychlor	I	3	4	23	0.22	1.65	7.6	3.0	176	24
	II	3	2	23	0.23	1.72	7.7	4.0	192	30
	III	4	2	24	0.20	1.50	7.7	2.0	196	53
	IV	4	4	20	0.22	1.86	6.4	4.5	132	16
Average		3.5	3.0	22	0.22	1.68	7.4	3.4	174	31
Aldrin, DDT	I	2	5	25	0.24	1.74	7.2	3.0	152	59
	II	3	2	24	0.26	1.59	7.5	10.0	188	32
	III	2	2	23	0.20	1.47	7.5	2.0	164	78
	IV	4	4	21	0.24	2.34	6.4	4.5	192	35
Average		2.8	3.2	23	0.24	1.78	7.2	4.9	174	51
Toxaphene, DDT	I	4	4	25	0.26	1.95	6.1	4.0	160	70
	II	3	2	23	0.22	1.65	7.5	1.5	124	56
	III	2	2	22	0.20	2.16	7.8	1.0	232	78
	IV	4	4	20	0.25	2.18	6.3	8.0	304	26
Average		3.2	3.0	22	0.23	1.98	6.9	3.6	205	58
Average for treatments		3.0	3.0	23	0.23	1.81	7.1	4.2	183	41

Table 21. Analyses of variance by blocks of variables studied, first crop alfalfa. Ames, 1951.

Source of variation	Degrees of freedom	Mean squares	F.
	Honey bee populations		
Replications	3	24.33	2.53
Treatments	3	5.50	<1
Error	9	9.61	
	Rate of honey bee visits to flowers		
Replications	3	755.33	1.50
Treatments	3	180.17	<1
Error	9	502.06	
	Lygus sp.		
Replications	3	0.38	<1
Treatments	3		
Insecticides *vs.* check	1	3.72	6.91*
Insecticides	2	0.92	1.70
Error	9	0.54	
	Leafhoppers		
Replications	3	0.015	<1
Treatments	3		
Insecticides *vs.* check	1	0.80	16.24**
Insecticides	2	0.02	<1
Error	9	0.05	
	Stand		
Replications	3	2.17	19.73**
Treatments	3	0.83	7.54**
Error	9	0.11	
	Elevation		
Replications	3	2.73	2.33
Treatments	3	0.06	<1
Error	9	1.17	
	Plant height		
Replications	3	13.42	13.03**
Treatments	3	0.75	<1
Error	9	1.03	

* Significant at 5 percent probability
** Significant at 1 percent probability

Table 21. (Continued)

Source of variation	Degrees of freedom	Mean squares	F.
	Plant phosphorus		
Replications	3	27.00	1.31
Treatments	3	28.33	1.38
Error	9	20.56	
	Plant potassium		
Replications	3	8,171.33	5.69*
Treatments	3	2,560.67	1.78
Error	9	1,436.89	
	Soil pH		
Replications	3	454.92	11.30**
Treatments	3	82.25	2.04
Error	9	40.25	
	Available phosphorus		
Replications	3	9,572.95	3.04
Treatments	3	1,122.92	<1
Error	9	3,145.13	
	Available potassium		
Replications	3	13,497.33	1.40
Treatments	3	3,492.00	<1
Error	9	9,628.89	
	Seed yield		
Replications	3	5,021.58	14.55**
Treatments	3		
Insecticides *vs.* check	1	5,250.08	15.21**
Insecticides	2	3,114.34	9.02*
Error	9	345.14	

* Significant at 5 percent probability
** Significant at 1 percent probability

accurate picture, because various species of wild bees were seen on the alfalfa during the experiment. A few cantharids were observed tripping alfalfa in 1950; therefore, a record of their abundance was kept in 1951, but none was observed on the first crop plots.

Honey bees were distributed in almost equal numbers over the experimental plots, as indicated by Table 17. The analysis of variance showed that there was no significant difference in the number of honey bees counted in plots of different insecticide treatments or on replications (Table 21).

Rate of honey bee visits to flowers. The over-all average rate honey bees visited first crop alfalfa flowers was 9.1 flowers per 30 seconds (Tables 16 and 17). This rate appeared to be fairly uniform for all plots regardless of the insecticide treatment, and differences in the rates of visitation among treatments or replications were not statistically significant.

Honey bees were observed visiting 1,077 flowers, and of this number, 12, or 1.11 percent, were tripped; most of this tripping was accidental.

Injurious insects. *Lygus* sp.[1] were the most prevalent injurious insects observed on the first crop alfalfa (Tables 16 and 18). Differences in *Lygus* populations on blocks of different insecticide treatment were highly significant, as shown in Table 21. Both combinations of insecticides (aldrin plus DDT and toxaphene plus DDT) controlled lygus bugs

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[1] The species most commonly found was *Lygus oblineatus* (Say); some *Lygus elisus* Van Duzee were also collected.

effectively, whereas methoxychlor was relatively ineffective.

Leafhoppers[1] were scarce but the check plots had populations that were significantly higher than those of treated plots. The number of leafhoppers found on blocks where the three different insecticides were applied did not vary significantly.

Alfalfa plant bugs, Adelphocoris lineolatus (Goeze), rapid plant bugs, Adelphocoris rapidus (Say), and grasshoppers[2] were present only in small numbers on the first crop alfalfa.

Climatological factors. Observations of climatological variables were not analyzed statistically. However, the mean values of wind velocity, light intensity, air temperature, relative humidity, vapor pressure deficit, and atmometer readings are given in Tables 16 and 19. With the exception of the light readings, there was little variation in the weather data associated with treatments; there was no apparent reason for the differences in light intensity.

Agronomic factors. There was an uneven stand in the blocks of first crop alfalfa, as indicated by the means (Tables 16 and 20), and by the analysis of variance (Table 21), which shows statistically significant differences in stands among both replications and treatments. The means for replications in Table 20 disclose some variation in elevation, but these differences were not statistically significant (Table 21). The differences in plant height were significant among replications. The means in Table 20 show that alfalfa plants in the check plots were the tallest

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[1] Mostly Empoasca fabae (Harr.)
[2] Mostly of the family Locustidae

and those sprayed with methoxychlor were the shortest. There was a highly significant mean difference in plant height among replications. There was no significant variation in percentage of plant phosphorus, but mean differences in plant potassium were significant among replications at the 5 percent level (Table 21).

Mean differences in soil pH among replications of first crop alfalfa were highly significant (Table 21), but there were no significant differences in available phosphorus or potassium in the soil. The means in Table 20 reveal that the low soil pH in the toxaphene-DDT plots and the high pH in the methoxychlor plots were probably the main sources of variation in pH.

Seed yields were very low (Table 20), but the mean differences in yields from check plots compared to plots sprayed with insecticides were highly significant (Table 21). Plots sprayed with aldrin plus DDT or toxaphene plus DDT had significantly higher seed yields than those sprayed with methoxychlor.

Second crop alfalfa

Tables 22 and 23 are summaries of the means for the variables studied on second crop alfalfa; more detailed data for each of the factors considered are contained in Tables 24 through 28. The analyses of variance are given in Tables 29 and 30, and correlation coefficients and regression equations are presented in Tables 31 and 32. Figures 30, 31, 32, and 33 show the regressions of seed yields and the rate of honey bee visits to flowers on the several independent variables that were considered.

Insect pollinators. Wild bees and can- (text continued on page 152)

Table 22. Summary of means of variables considered in study of second crop alfalfa seed production. Ames, 1951.

Factor studied	Mean for treatment: Check	Meth-oxy-chlor	Aldrin, DDT	Toxa-phene, DDT	Average of all treat-ments
Insect pollinators (no./6 sq. yds.)					
Wild bees	0.00	0.03	0.06	0.00	0.02
Cantharids	0.03	0.09	0.00	0.00	0.03
Honey bees	3.8	7.2	8.4	8.8	7.1
Honey bee activity					
No. flowers visited/30 secs.	9.9	9.6	9.5	9.7	9.7
No. flowers tripped by honey bees[a]	3	2	5	0	10[b]
Injurious insects (no./sweep)					
Lygus sp.	6.6	4.3	1.2	1.3	3.4
Leafhoppers	4.8	1.1	0.8	0.8	1.9
Alfalfa plant bugs	0.34	0.00	0.03	0.06	0.11
Rapid plant bugs	0.09	0.00	0.00	0.00	0.02
Grasshoppers	1.59	0.00	0.00	0.00	0.40
Climatological factors					
Wind velocity (mph)	3.9	3.9	3.9	3.9	3.9
Light (10 ft. candles)	249	251	240	250	248
Air temperature (° F.)	78.9	78.9	79.1	79.1	79.0
Relative humidity	65.1	65.3	63.9	65.3	64.9
Vapor pressure deficit	9.0	9.0	9.4	9.0	9.1
Atmometer reading (cc./hr.)	2.3	2.3	2.3	2.3	2.3
Agronomic factors					
Stand (1-4)	2.2	2.8	2.2	3.0	2.6
Elevation (1-6)	2.5	3.0	2.5	3.2	2.8
Plant height (in.)	22	20	20	20	20
Plant P (%)	0.20	0.23	0.22	0.22	0.22
Plant K (%)	1.38	1.41	1.42	1.52	1.44
Soil pH	7.3	7.1	7.4	7.3	7.3
Available P (lbs./A.)	2.2	2.4	2.2	2.6	2.4
Available K (lbs./A.)	152	169	185	160	166
Seed yield (lbs./A.)	11	21	55	45	33

[a] Totals, not averages
[b] Total flowers tripped of 3,706 visited, or 0.27 percent

Table 23. Summary of means for honey bee data, second crop alfalfa. Ames, 1951.

Factor studied	Mean for treatment: Check	Meth-oxy-chlor	Aldrin, DDT	Toxa-phene, DDT	Average all treat-ments
Number of honey bees per 6 square yards	4.1	8.5	8.5	9.6	7.7
Number of flowers visited per 30 seconds	9.6	9.2	9.3	9.5	9.4
Number of bees collected per person per minute	17.6	17.1	18.9	17.5	17.8
Number of bees examined	13.4	13.8	15.2	15.3	14.5
Percentage of bees carrying					
Pollen	0.0	0.0	0.0	0.0	0.0
Pollen only	0.0	0.0	0.0	0.0	0.0
Both pollen and nectar ..	0.0	0.0	0.0	0.0	0.0
Nectar only	73.6	72.2	69.6	64.6	70.0
Nectar	73.6	72.2	69.6	64.6	70.0
No load	26.3	27.8	30.3	35.4	30.0
No pollen	100.0	100.0	100.0	100.0	100.0
Average load size					
Pollen	0.0	0.0	0.0	0.0	0.0
Nectar	2.0	1.8	1.8	1.8	1.8
Percent sugar in nectar	26.3	25.0	25.2	26.3	25.7

Table 24. Means of insect pollinators and honey bee activity by replications and treatments, second crop alfalfa. Ames, 1951.

Treatment	Replication	No. insect pollinators (per 6 sq. yds.) Wild bees	Can-tharids	Honey bees	No. flowers visited by honey bees (per 30 secs.)	No. flowers tripped by honey bees[a]
Check	I	0.00	0.00	3.0	10.0	0
	II	0.00	0.00	2.8	9.0	0
	III	0.00	0.00	2.9	10.8	1
	IV	0.00	0.12	6.8	9.7	2
Average		0.00	0.03	3.8	9.9	3
Methoxychlor	I	0.12	0.00	5.9	9.5	1
	II	0.00	0.00	10.1	10.4	0
	III	0.00	0.25	7.0	9.6	0
	IV	0.00	0.12	6.0	9.1	1
Average		0.03	0.09	7.2	9.6	2
Aldrin, DDT	I	0.00	0.00	10.2	9.2	1
	II	0.12	0.00	10.5	10.0	0
	III	0.00	0.00	7.0	10.4	1
	IV	0.12	0.00	5.9	8.5	3
Average		0.06	0.00	8.4	9.5	5
Toxaphene, DDT	I	0.00	0.00	9.8	9.8	0
	II	0.00	0.00	12.0	10.0	0
	III	0.00	0.00	7.0	9.4	0
	IV	0.00	0.00	6.2	9.6	0
Average		0.00	0.00	8.8	9.7	0
Average for treatments		0.02	0.03	7.1	9.7	10[b]

[a] Totals, not averages [b] Total flowers tripped of 3,706 visited, or 0.27 percent

Table 25. Means of injurious insects by replications and treatments, second crop alfalfa. Ames, 1951.

Treatment	Replication	Injurious insects (number/sweep)				
		Lygus sp.	Leaf-hoppers	Alfalfa plant bugs	Rapid plant bugs	Grass-hoppers
Check	I	5.2	5.2	0.25	0.00	3.12
	II	13.0	6.8	1.00	0.38	1.37
	III	3.1	2.9	0.12	0.00	0.75
	IV	5.1	4.1	0.00	0.00	1.12
Average		6.6	4.8	0.34	0.09	1.59
Methoxychlor	I	3.9	0.8	0.00	0.00	0.00
	II	6.6	1.8	0.00	0.00	0.00
	III	4.2	0.9	0.00	0.00	0.00
	IV	2.5	1.1	0.00	0.00	0.00
Average		4.3	1.1	0.00	0.00	0.00
Aldrin, DDT	I	1.0	0.4	0.00	0.00	0.00
	II	2.0	1.4	0.00	0.00	0.00
	III	0.9	0.6	0.12	0.00	0.00
	IV	1.0	0.6	0.00	0.00	0.00
Average		1.2	0.8	0.03	0.00	0.00
Toxaphene, DDT	I	1.4	0.8	0.12	0.00	0.00
	II	1.9	1.4	0.00	0.00	0.00
	III	0.8	0.5	0.12	0.00	0.00
	IV	1.2	0.8	0.00	0.00	0.00
Average		1.3	0.8	0.06	0.00	0.00
Average for treatments		3.4	1.9	0.11	0.02	0.40

Table 26. Means of climatological factors by replications and treatments, second crop alfalfa. Ames, 1951.

Treatment	Replication	Climatological factors: Wind velocity (mph)	Light (10 ft. candles)	Air temperature (° F.)	Relative humidity	Vapor pressure deficit	Atmometer reading (cc./hr.)
Check	I	4.0	252	78.4	62.6	9.9	2.1
	II	4.0	216	79.9	65.1	9.2	2.3
	III	3.5	265	79.5	65.2	9.0	2.6
	IV	4.0	265	77.8	67.4	8.0	2.3
Average		3.9	249	78.9	65.1	9.0	2.3
Methoxychlor	I	4.0	267	78.4	63.1	9.6	2.1
	II	4.0	213	79.5	64.7	9.1	2.3
	III	3.5	263	80.2	64.6	9.5	2.6
	IV	4.0	260	77.8	68.8	7.9	2.3
Average		3.9	251	78.9	65.3	9.0	2.3
Aldrin, DDT	I	4.0	252	79.2	59.2	11.0	2.1
	II	4.0	209	79.5	66.0	9.0	2.3
	III	3.5	240	80.0	64.9	9.2	2.6
	IV	4.0	259	78.0	65.6	8.5	2.3
Average		3.9	240	79.1	63.9	9.4	2.3
Toxaphene, DDT	I	4.0	232	79.5	61.5	10.4	2.1
	II	4.0	215	79.1	67.1	8.6	2.3
	III	3.5	270	79.5	65.2	9.0	2.6
	IV	4.0	284	78.5	67.5	8.1	2.3
Average		3.9	250	79.1	65.3	9.0	2.3
Average for treatments		3.9	248	79.0	64.9	9.1	2.3

Table 27. Means of agronomic factors by replications and treatments, second crop alfalfa. Ames, 1951.

		Agronomic factors								
				Plant			Soil			
Treatment	Replication	Stand (1-4)	Elevation (1-6)	Height (in.)	P (%)	K (%)	pH	Available P (lbs./A.)	Available K (lbs./A.)	Seed yield (lbs./A.)
Check	I	2	2	17	0.20	1.20	7.7	1.0	124	4
	II	3	4	24	0.22	1.52	6.6	4.0	136	2
	III	2	2	20	0.18	1.32	7.6	2.0	176	22
	IV	2	2	22	0.22	1.50	7.3	2.0	172	16
Average		2.2	2.5	21	0.20	1.38	7.3	2.2	152	11
Methoxychlor	I	2	2	21	0.22	1.26	7.6	1.0	176	21
	II	4	4	20	0.28	1.50	6.9	3.5	164	25
	III	3	4	23	0.20	1.38	6.2	3.5	144	17
	IV	2	2	19	0.21	1.51	7.8	1.5	192	21
Average		2.8	3.0	20	0.23	1.41	7.1	2.4	169	21
Aldrin, DDT	I	1	2	21	0.20	1.38	7.7	1.0	180	75
	II	4	4	20	0.24	1.56	6.8	4.0	172	77
	III	2	2	20	0.20	1.37	7.6	2.0	208	45
	IV	2	2	17	0.24	1.38	7.7	2.0	180	24
Average		2.2	2.5	20	0.22	1.42	7.4	2.2	185	55
Toxaphene, DDT	I	3	3	21	0.21	1.41	7.7	1.0	160	48
	II	4	4	21	0.26	1.62	6.9	4.5	160	56
	III	3	3	22	0.21	1.41	6.9	3.0	156	51
	IV	2	3	18	0.18	1.65	7.7	2.0	164	25
Average		3.0	3.2	20	0.22	1.52	7.3	2.6	160	45
Average for treatments		2.6	2.8	20	0.22	1.44	7.3	2.4	166	33

Table 28. Means of nectar and pollen data and other honey bee data by replications a

Treatment	Replication	No. flowers visited by honey bees (per 30 secs.)	No. honey bees: Per 6 sq. yds.	No. honey bees: Collected per person per minute	No. honey bees: Examined	Percent bees: Pollen	Percent bees: Pollen only	Percent bees: Both pollen and nectar
Check	I	9.6	4.0	12.6	12.8	0	0	0
	II	8.2	3.4	16.4	12.4	0	0	0
	III	10.4	3.6	19.0	14.0	0	0	0
	IV	10.0	5.4	22.4	14.6	0	0	0
Average		9.6	4.1	17.6	13.4	0	0	0
Methoxychlor	I	9.0	7.6	13.2	12.2	0	0	0
	II	10.1	12.2	17.6	12.8	0	0	0
	III	9.2	8.6	22.2	14.6	0	0	0
	IV	8.5	5.6	15.4	15.8	0	0	0
Average		9.2	8.5	17.1	13.8	0	0	0
Aldrin, DDT	I	9.0	9.6	12.0	13.8	0	0	0
	II	10.3	12.0	20.0	19.2	0	0	0
	III	10.5	7.0	20.8	13.8	0	0	0
	IV	7.4	5.4	22.8	14.2	0	0	0
Average		9.3	8.5	18.9	15.2	0	0	0
Toxaphene, DDT	I	9.9	9.8	15.2	15.2	0	0	0
	II	9.7	14.2	22.4	13.6	0	0	0
	III	8.9	8.4	17.6	16.4	0	0	0
	IV	9.3	5.6	14.8	16.0	0	0	0
Average		9.5	9.6	17.5	15.3	0	0	0
Average for treatments		9.4	7.7	17.8	14.5	0	0	0

ther honey bee data by replications and treatments, second crop alfalfa. Ames, 1951.

honey bees		Percent bees collected carrying							Average load size		Percent
ollected er person er minute	Exam-ined	Pollen	Pollen only	Both pollen and nectar	Nectar only	Nectar	No load	No pollen	Pol-len	Nec-tar	sugar in nectar
12.6	12.8	0	0	0	80.0	80.0	19.8	100	0	2.2	28.2
16.4	12.4	0	0	0	70.0	70.0	30.0	100	0	2.0	25.2
19.0	14.0	0	0	0	74.6	74.6	25.2	100	0	1.8	27.8
22.4	14.6	0	0	0	69.8	69.8	30.2	100	0	2.0	24.0
17.6	13.4	0	0	0	73.6	73.6	26.3	100	0	2.0	26.3
13.2	12.2	0	0	0	73.8	73.8	26.0	100	0	1.8	26.6
17.6	12.8	0	0	0	79.8	79.8	20.0	100	0	2.0	24.6
22.2	14.6	0	0	0	71.2	71.2	28.8	100	0	1.8	26.8
15.4	15.8	0	0	0	63.8	63.8	36.2	100	0	1.6	22.0
17.1	13.8	0	0	0	72.2	72.2	27.8	100	0	1.8	25.0
12.0	13.8	0	0	0	73.8	73.8	26.2	100	0	1.4	26.8
20.0	19.2	0	0	0	57.6	57.6	42.4	100	0	1.8	23.6
20.8	13.8	0	0	0	73.8	73.8	26.2	100	0	2.2	29.0
22.8	14.2	0	0	0	73.4	73.4	26.4	100	0	1.6	21.4
18.9	15.2	0	0	0	69.6	69.6	30.3	100	0	1.8	25.2
15.2	15.2	0	0	0	59.0	59.0	41.0	100	0	2.0	27.0
22.4	13.6	0	0	0	75.0	75.0	25.0	100	0	1.8	27.2
17.6	16.4	0	0	0	63.0	63.0	37.0	100	0	1.8	28.2
14.8	16.0	0	0	0	61.2	61.2	38.8	100	0	1.8	22.8
17.5	15.3	0	0	0	64.6	64.6	35.4	100	0	1.8	26.3
17.8	14.5	0	0	0	70.0	70.0	30.0	100	0	1.8	25.7

Table 29. Analyses of variance by blocks of variables studied, second crop alfalfa. (Data based on eight 2-day observation periods.) Ames, 1951.

Source of variation	Degrees of freedom	Mean squares	F.
	Honey bee populations		
Replications	3	435.67	1.54
Treatments	3		
Insecticides *vs.* check	1	3,536.00	12.52**
Insecticides	2	158.00	<1
Error	9	282.33	
	Rate of honey bee visits to flowers		
Replications	3	3,214.67	1.33
Treatments	3	525.00	<1
Error	9	2,413.00	
	Lygus sp.		
Replications	3	732.73	3.12
Treatments	3		
Insecticides *vs.* check	1	4,622.69	19.71**
Insecticides	2	292.50	1.25
Error	9	234.51	
	Leafhoppers		
Replications	3	116.56	3.84
Treatments	3		
Insecticides *vs.* check	1	2,836.69	93.50**
Insecticides	2	9.75	<1
Error	9	30.34	
	Light intensity		
Replications	3	146,960.33	16.69**
Treatments	3	6,810.33	<1
Error	9	8,804.00	
	Air temperature		
Replications	3	163.58	12.51**
Treatments	3	5.75	<1
Error	9	13.08	
	Relative humidity		
Replications	3	1,474.33	17.03**
Treatments	3	113.33	1.31
Error	9	86.56	

** Significant at 1 percent probability

Table 29. (Continued)

Source of variation	Degrees of freedom	Mean squares	F.
	Vapor pressure deficit		
Replications	3	189.06	21.81**
Treatments	3	10.56	1.22
Error	9	8.67	
	Stand		
Replications	3	2.73	11.87**
Treatments	3	0.56	2.43
Error	9	0.23	
	Elevation		
Replications	3	2.73	9.75**
Treatments	3	0.56	2.00
Error	9	0.28	
	Plant height		
Replications	3	4.75	1.08
Treatments	3	1.42	<1
Error	9	4.36	
	Plant phosphorus		
Replications	3	1,348.00	5.33*
Treatments	3	228.00	<1
Error	9	252.89	
	Plant potassium		
Replications	3	32,494.66	12.91**
Treatments	3	9,230.66	3.67
Error	9	2,517.78	
	Soil pH		
Replications	3	4,665.33	4.86*
Treatments	3	452.00	<1
Error	9	960.44	
	Available phosphorus		
Replications	3	41,333.33	29.06**
Treatments	3	800.00	<1
Error	9	1,422.22	

* Significant at 5 percent probability
** Significant at 1 percent probability

Table 29. (Continued)

Source of variation	Degrees of freedom	Mean squares	F.
	Available potassium		
Replications	3	20,906.67	<1
Treatments	3	51,285.33	2.37
Error	9	21,646.22	
	Seed yield		
Replications	3	16,878.67	1.17
Treatments	3		
Insecticides *vs.* check	1	166,145.00	11.52**
Insecticides	2	79,109.50	5.49*
Error	9	14,418.22	

* Significant at 5 percent probability
** Significant at 1 percent probability

Table 30. Analyses of variance by blocks of honey bee and nectar data, second crop alfalfa. (Data based on five 2-day observation periods.) Ames, 1951.

Source of variation	Degrees of freedom	Mean squares	F.
	Honey bee populations		
Replications	3	427.40	4.22*
Treatments	3		
Insecticides *vs.* check	1	1,692.19	16.71**
Insecticides	2	36.75	<1
Error	9	101.28	
	Rate of honey bee visits to flowers		
Replications	3	1,685.75	<1
Treatments	3	232.75	<1
Error	9	2,414.03	
	Rate bees were collected		
Replications	3	930.08	3.79
Treatments	3	60.92	<1
Error	9	245.64	
	Honey bees with no nectar load		
Replications	3	412.50	<1
Treatments	3	1,617.83	1.15
Error	9	1,409.33	
	Honey bees carrying nectar only		
Replications	3	406.92	<1
Treatments	3	1,580.25	1.14
Error	9	1,388.17	
	Nectar load size		
Replications	3	0.50	<1
Treatments	3	1.17	<1
Error	9	1.33	
	Percent sugar in nectar		
Replications	3	579.67	23.39**
Treatments	3	48.67	1.97
Error	9	24.78	

* Significant at 5 percent probability
** Significant at 1 percent probability

Table 31. Correlation coefficients of variables studied, based on seasonal block averages, second crop alfalfa. Ames, 1951.

	Seed yield	Honey bee populations	Rate of honey bee visits to flowers	Plant phosphorus	Plant potassium
Honey bee populations ..	0.698*				
Rate of honey bee visits to flowers	0.320				
Lygus sp.	-0.608*	-0.482	-0.655*		
Leafhoppers	-0.622*				
Light		-0.277	-0.217		
Air temperature		-0.046	-0.147		
Relative humidity		-0.129	0.307		
Vapor pressure deficit .		0.131	-0.353		
Plant phosphorus	-0.049	0.362	0.020		
Plant potassium	0.511	0.382	0.206		
Soil pH	0.020	-0.175	0.548		
Available phosphorus ...	-0.063	0.112	-0.555	0.059	-0.014
Available potassium	0.415	0.259	0.517	0.044	0.236

* Significant at 5 percent probability

Table 32. Error regression equations and correlation coefficients for variables studied, second crop alfalfa. Ames, 1951.

Equation number	Regression equation[a]	Degrees of freedom	Correlation coefficients r
1	$\hat{Y}_1 = -4.7696X_1 + 49.22$	8	-0.608*
2	$\hat{Y}_1 = -13.5593X_2 + 58.76$	8	-0.622*
3	$\hat{Y}_1 = -3.6731X_7 + 41.08$	8	-0.049
4	$\hat{Y}_1 = 12.2383X_8 - 143.23$	8	0.511
5	$\hat{Y}_1 = 0.7913X_9 + 27.22$	8	0.020
6	$\hat{Y}_1 = -2.0000X_{10} + 37.80$	8	-0.063
7	$\hat{Y}_1 = 0.3385X_{11} - 23.19$	8	0.415
8	$\hat{Y}_1 = 4.9854X_{12} - 2.40$	8	0.698*
9	$\hat{Y}_1 = 7.8183X_{13} - 42.84$	8	0.320
10	$\hat{Y}_2 = -0.5285X_1 + 8.90$	8	-0.482
11	$\hat{Y}_2 = -0.0496X_3 + 19.40$	8	-0.277
12	$\hat{Y}_2 = -0.2123X_4 + 23.87$	8	-0.046
13	$\hat{Y}_2 = -0.2327X_5 + 22.20$	8	-0.129
14	$\hat{Y}_2 = 0.7494X_6 + 0.28$	8	0.131
15	$\hat{Y}_2 = 3.8225X_7 - 1.31$	8	0.362
16	$\hat{Y}_2 = 1.2780X_8 - 11.30$	8	0.382
17	$\hat{Y}_2 = -0.9463X_9 + 14.01$	8	-0.174
18	$\hat{Y}_2 = 0.5000X_{10} + 5.90$	8	0.112
19	$\hat{Y}_2 = 0.0296X_{11} + 2.19$	8	0.259

[a] See key to X and Y values at end of table

* Significant at 5 percent probability

Table 32. (Continued)

Equation number	Regression equation[a]	Degrees of freedom	Correlation coefficients r
20	$\hat{Y}_3 = -0.2102X_1 + 10.41$	8	-0.655*
21	$\hat{Y}_3 = -0.0114X_3 + 12.53$	8	-0.217
22	$\hat{Y}_3 = -0.1996X_4 + 25.47$	8	-0.147
23	$\hat{Y}_3 = 0.1619X_5 - 0.81$	8	0.307
24	$\hat{Y}_3 = -0.5880X_6 + 15.05$	8	-0.353
25	$\hat{Y}_3 = 0.0611X_7 + 7.57$	8	0.020
26	$\hat{Y}_3 = 0.2015X_8 + 6.80$	8	0.206
27	$\hat{Y}_3 = 0.8680X_9 + 3.36$	8	0.548
28	$\hat{Y}_3 = -0.7234X_{10} + 11.44$	8	-0.555
29	$\hat{Y}_3 = 0.0173X_{11} + 6.83$	8	0.517

[a] Key to X and Y values:

$\hat{Y}_1$ = Seed yield

$\hat{Y}_2$ = Honey bee populations

$\hat{Y}_3$ = Rate of honey bee visits to flowers

X_1 = *Lygus* sp.

X_2 = Leafhoppers

X_3 = Light intensity

X_4 = Air temperature

X_5 = Relative humidity

X_6 = Vapor pressure deficit

X_7 = Plant phosphorus

X_8 = Plant potassium

X_9 = Soil pH

X_{10} = Available phosphorus

X_{11} = Available potassium

X_{12} = Honey bee populations

X_{13} = Rate of honey bee visits to flowers

* Significant at 5 percent probability

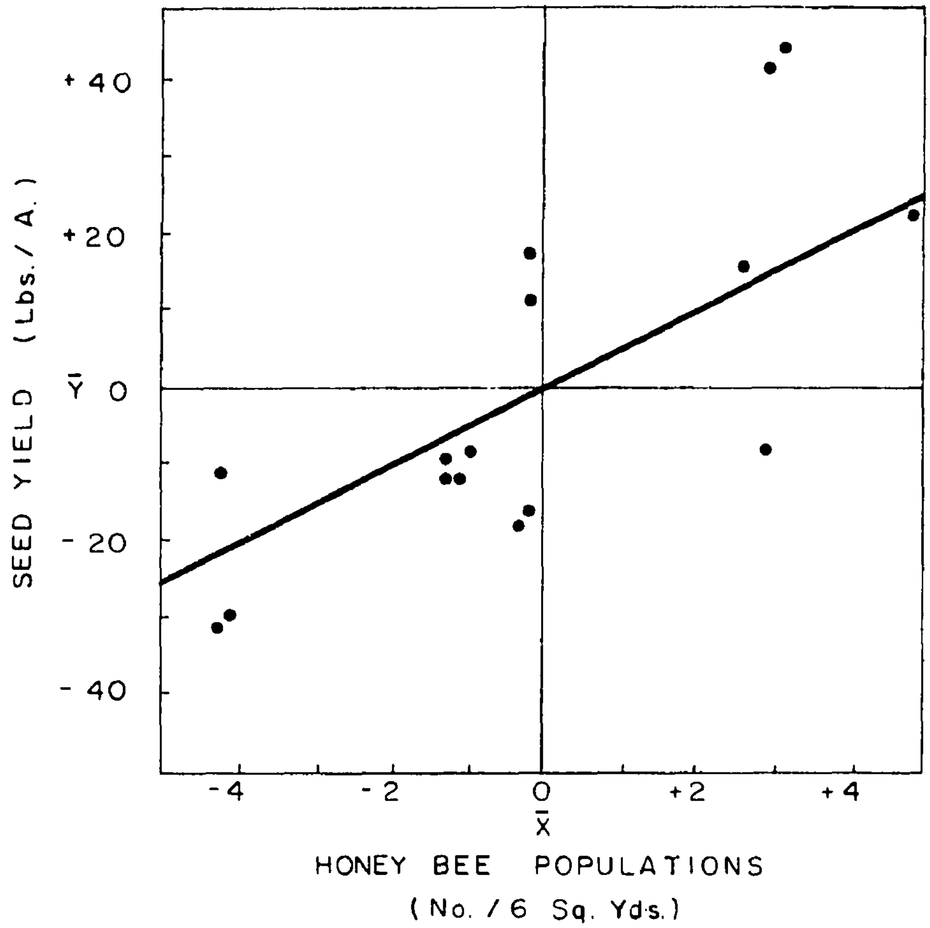

Fig. 30. Error regression of seed yield on honey bee populations, second crop alfalfa. Ames, 1951.

$\bar{y}$ = 33 pounds per acre, mean seed yield

$\bar{x}$ = 7.1 bees per 6 square yards, mean honey bee population

$\hat{Y} = 4.9854X - 2.40$

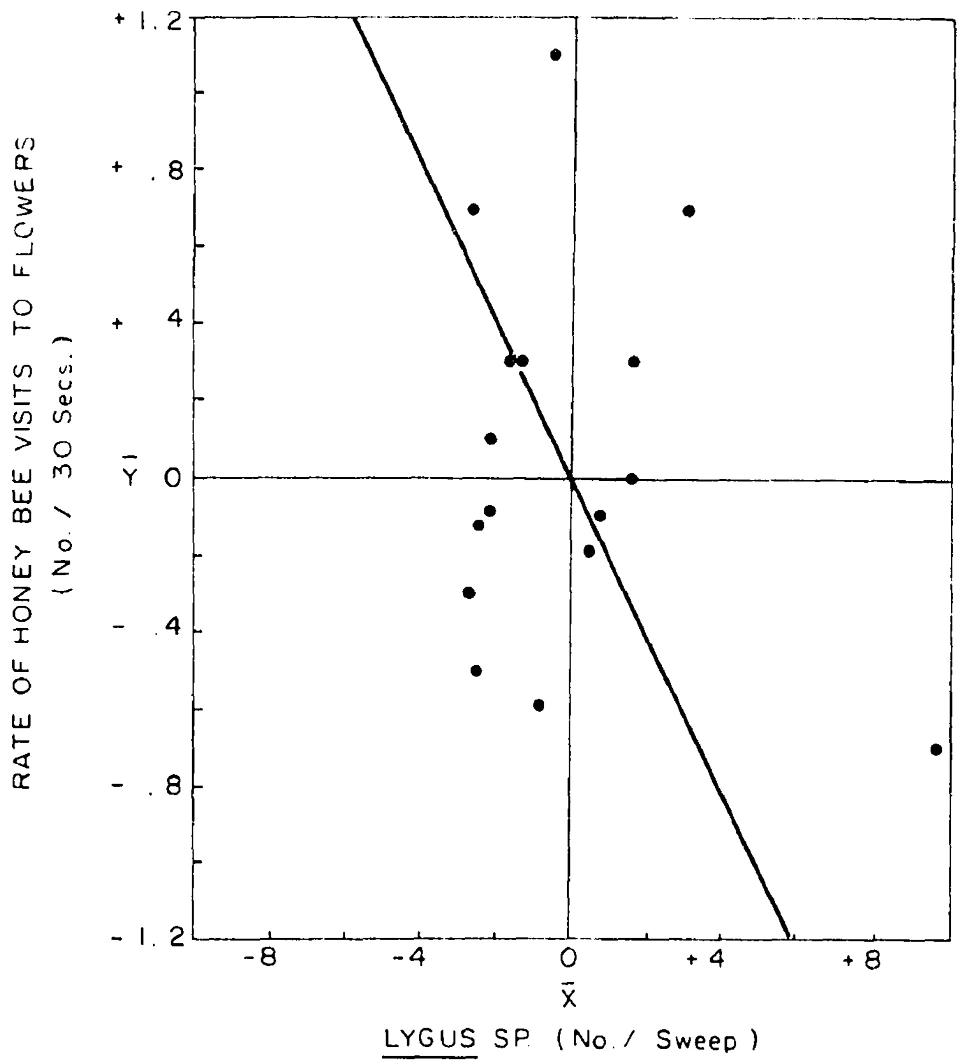

Fig. 31. Error regression of rate of honey bee visits to flowers on number of lygus bugs, second crop alfalfa. Ames, 1951.

$\bar{y}$ = 9.7 per 30 seconds, mean rate of honey bee visits to flowers

$\bar{x}$ = 3.4 per sweep, mean number of lygus bugs

$\hat{Y} = -0.2102X + 10.41$

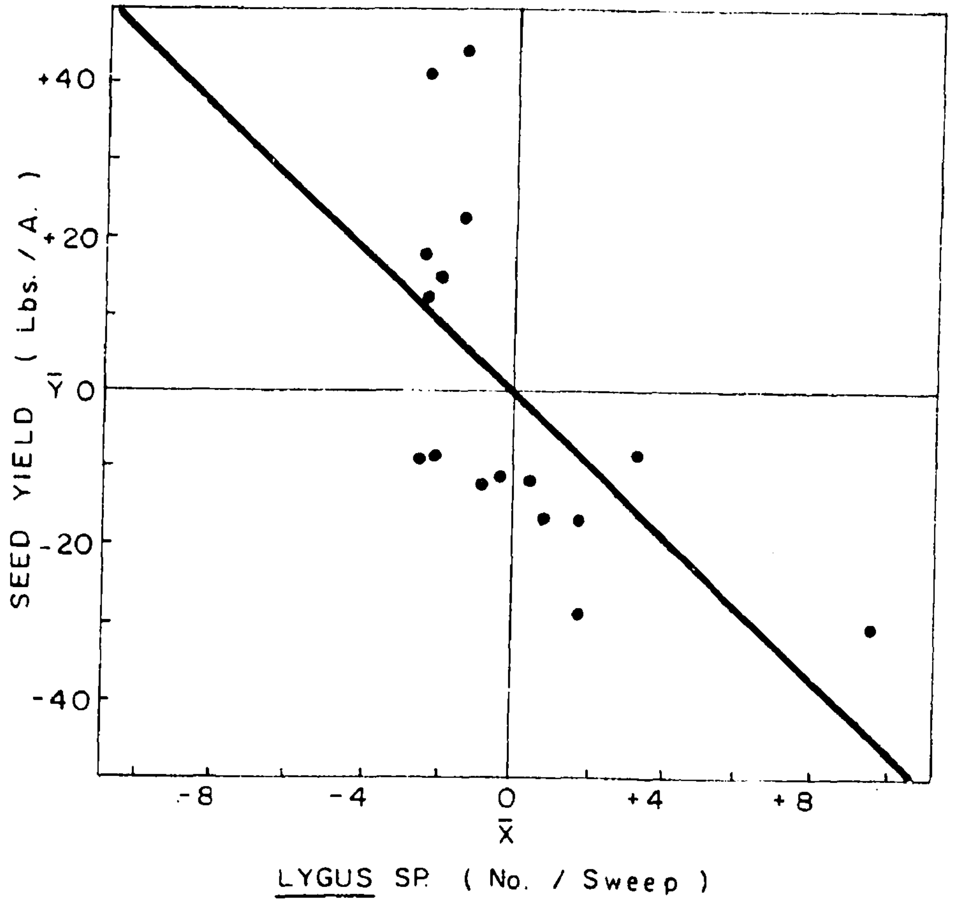

Fig. 32. Error regression of seed yield on lygus bugs, second crop alfalfa. Ames, 1951.

$\bar{y}$ = 33 pounds per acre, mean seed yield

$\bar{x}$ = 3.4 per sweep, mean number of lygus bugs

$\hat{Y} = -4.7696X + 49.22$

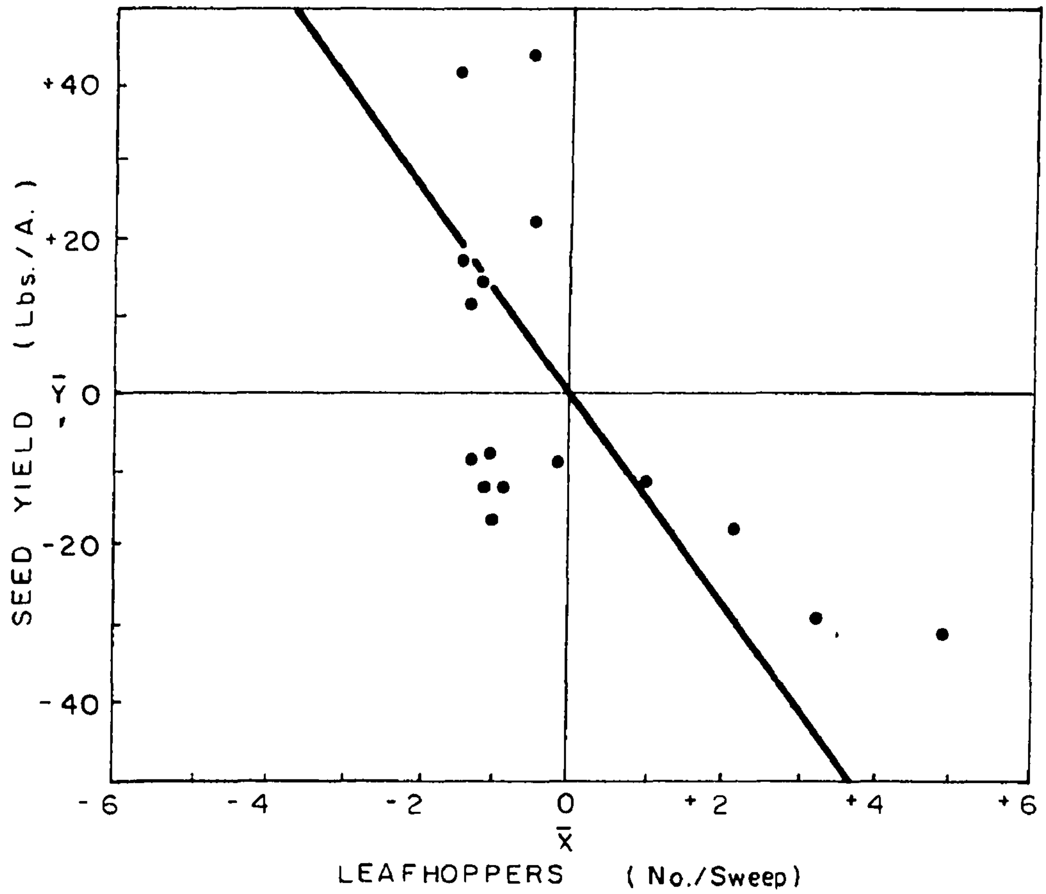

Fig. 33. Error regression of seed yield on leafhoppers, second crop alfalfa. Ames, 1951.

$\bar{y}$ = 33 pounds per acre, mean seed yield

$\bar{x}$ = 1.9 per sweep, mean number of leafhoppers

$\hat{Y} = -13.5593X + 58.76$

tharids were rarely seen in the square-yard plots of second crop alfalfa (Tables 22 and 24). Honey bee populations varied from an average of 3.8 per 6 square yards on the check blocks to 8.8 on blocks sprayed with toxaphene-DDT (Tables 22 and 24). The differences in bee populations between check plots and those where insecticides were applied were highly significant, but differences in bee populations on plots treated with various insecticides were not (Table 29).

The only significant correlation between honey bee populations and other variables studied was with seed yield; this correlation was significant at the 5 percent level ($r = 0.698$, Table 31). The regression of seed yields on honey bee populations (Figure 30 and Table 32) shows that an increase of 4.98 pounds of seed per acre might be expected with an increase of one bee per 6 square yards under the conditions of this experiment. There appeared to be a tendency toward a negative correlation between populations of honey bees and lygus bugs, but this relationship was not definitely established by the data.

Rate of honey bee visits to flowers. Honey bees visited an average of 9.7 alfalfa flowers per 30 seconds on second crop alfalfa (Tables 22 and 24). There were no significant differences in the rate of honey bee visits to flowers (Table 29), but the rate honey bees visited flowers had a significant negative correlation with lygus bug numbers ($r = -0.655$, Table 31). However, the regression of rate of honey bee visits to flowers on lygus bug numbers (Figure 31 and Table 32) indicates that there was actually little relationship between *Lygus* populations and the rate bees visited flowers. It seems likely that one observation shown in the lower left corner of the graph and the cluster of means over the center range might have produced this pseudocorrelation.

The data in Table 31 show a high but nonsignificant correlation between the rate honey bees visited flowers and the following: soil pH ($r = 0.548$), available potassium ($r = 0.517$), and available phosphorus ($r = -0.555$).

The bees observed on second crop alfalfa visited a total of 3,706 alfalfa flowers, but they tripped only 10, or 0.27 percent of the flowers they visited.

Injurious insects. Lygus bug populations were reduced to a seasonal average of slightly more than one bug per sweep on areas sprayed with aldrin-DDT and toxaphene-DDT combination sprays, but they averaged 4.3 per sweep on blocks sprayed with methoxychlor and 6.6 on the control areas (Table 25). The analysis of variance indicated that the differences in the number of lygus bugs present on check and sprayed areas were highly significant, but that differences between insecticide treatments were not significant (Table 29).

The scatter of points in Figure 32 suggests that the regression of seed yield on lygus bugs is curvilinear. A sharp rise in seed yield seems to occur when about two lygus per sweep were present; the sharpness of the curve may indicate a threshold above which *Lygus* infestations seriously affected seed yields. Work by Haws (1949) indicated that the detrimental effects of lygus bugs on seed production decreased rapidly at a population of three or less per sweep. Regression Equation 1 (Table 32) indicates that under the conditions of these experiments seed yields might be expected to increase 4.77 pounds per acre with each decrease of one Lygus per sweep.

Methoxychlor controlled the leafhoppers effectively, but was relatively ineffective in controlling lygus bugs. The detrimental effect of leafhoppers on seed production appeared to be similar to that of lygus bugs or even more drastic. The relationship of leafhoppers to seed yields (Figure 33) also seemed to be curvilinear, with a sharp rise in seed yields when leafhoppers were reduced to an average of 0.5 per sweep. Regression Equation 2 (Table 32) indicates that an increase of 13.56 pounds of seed per acre might have been expected with each reduction of one leafhopper per sweep.

There were very few alfalfa plant bugs, rapid plant bugs, or grasshoppers present on the second crop alfalfa, as may be seen in Tables 22 and 25. These data were not statistically analyzed.

Climatological factors. The wind velocity during the experiment on second crop alfalfa averaged 3.9 miles per hour, and the means indicate that wind velocity was quite uniform on all treatments and replications (Tables 22 and 26).

The analysis of variance showed that differences in the following climatological factors were highly significant among replications: light intensity, air temperature, relative humidity, and vapor pressure deficit, but only small differences in these climatological factors were observed where different insecticides were applied (Table 29). Examination of the means in Table 26 discloses that the sequence of greatest to least values by replications was not the same for all of these weather factors, but the usual negative relationship of relative humidity to vapor pressure deficit is apparent.

Atmometer readings varied little and were not analyzed statistically, but the means show that there was an average evaporation rate of 2.3 cubic centimeters per hour during the time observations were made on second crop alfalfa.

Agronomic factors. Table 22 contains the summary of means of agronomic data; the block averages are shown in Table 27, and the analyses of variance are found in Table 29.

Differences in stand, elevation, plant height, plant phosphorus and potassium, soil pH, and available phosphorus and potassium were not significantly different among treatments. Except for plant height, available potassium, and seed yield, the differences in all of these variables were significant or highly significant among replications.

Differences in seed yields for insecticides *vs.* check plots were highly significant, and they were significant among insecticides at a probability of 5 percent (Table 29). Methoxychlor-treated plots had better seed yields than the checks but lower yields than plots sprayed with aldrin-DDT or toxaphene-DDT (Tables 22 and 27).

Examination of the means for agronomic factors in Table 27 shows that most of the variations associated with replications are due to differences in Replication II compared to the other three replications. Special attention is called to the comparison of these means for replications because they indicate that Replication II had the best stand, the highest elevation, the largest amounts of plant phosphorus, plant potassium, and available phosphorus, the lowest average soil pH, and the highest seed yield; also Replication II had the most bees per square yard and the lowest percentage of sugar in nectar. It should be noted that differences in bee populations were not significant for replications, but that the variation in percentage of sugar in nectar was highly significant.

The percentage of plant potassium and available potassium in the soil had a tendency toward a positive correlation with seed yields, but these correlations were not statistically significant (Table 31). There was a low correlation between phosphorus in the plants and available phosphorus in the soil, and a higher but insignificant correlation between potassium in the plants and available potassium in the soil. Little association was indicated between plant potassium and available phosphorus or between plant phosphorus and available potassium.

<u>Honey bee, nectar, and pollen data</u>. The results of studies on honey bee activities and their behavior in gathering nectar and/or pollen are shown in Tables 23 and 28; the analyses of variance based on these data are found in Table 30.

There were consistently more honey bees per square yard on plots where insecticides had been applied than there were on the control plots; the average number of bees per 6 square yards on the treated areas was 8.9 compared to 4.1 on check plots (Table 23). The differences between honey bee populations on the check and treated plots were highly significant, but they were not significant among blocks treated with different insecticides (Table 30).

The rate honey bees visited alfalfa flowers was quite uniform, as is shown by the means in Table 28 and the analysis of variance in Table 30. An average of 9.4 flowers was visited in 30 seconds.

It was thought that the rate bees could be collected for nectar samples might give some indication of the relative number of bees present and in this way confirm results of population counts made on square-yard plots. However, the average rate of 17.6 bees collected per person per minute was quite uniform on all plots even where counts on square-yard plots had indicated there were highly significant differences.

It was also thought that a tabulation of the number of bees examined to obtain adequate samples for nectar analysis might give information regarding the quantity of nectar being gathered by the bees. If, for example, it were necessary to examine a larger number of bees to obtain adequate samples of nectar for analysis, this might indicate that small quantities of nectar were available to the bees. The data shown in Tables 23 and 28 disclose that there were only slight differences in the number of bees that had to be examined from different areas to get adequate nectar samples. An average of 14.5 bees was examined to get 10 valid nectar readings.

Although each bee dissected to obtain a nectar sample was examined for pollen, no pollen was found on the hundreds of bees collected from alfalfa (Tables 23 and 28). An average of 70 percent of the bees examined were carrying nectar, and 30 percent of them had neither nectar nor pollen. The nectar loads collected by the bees on different blocks did not differ significantly in size (Table 30).

There were only slight differences in the percentage of sugar contained in nectar from blocks of different insecticide treatments, but the differences among replications were highly significant (Table 30). The means for replications show that the percentage of sugar in nectar collected from different replications varied from 22 to 28 percent (Table 28).

First crop red clover

A summary of the means of factors studied on first crop red clover is presented in Table 33. Tables 34 through 37 present block means for replications and treatments, and Table 38 contains the analyses of variance of these data.

Insect pollinators. Wild bees, cantharids, and honey bees were all scarce on the first crop red clover. There were more honey bees than wild bees or cantharids, but there was an average of only 0.1 honey bee per square yard observed on the first crop red clover (Tables 33 and 34). There were no consistent differences in the numbers of honey bees found on plots where different insecticides were applied (Table 38).

Rate of honey bee visits to flowers. Honey bees visited an average of 4.6 flowers in 30 seconds (Tables 33 and 34). The statistical analysis indicated that there were no consistent differences in the rate bees visited flowers among the insecticidal treatments or the replications (Table 38).

Injurious insects. Lygus bugs were the most prevalent injurious insects that were observed (Tables 33 and 35). The combination of toxaphene and DDT effectively controlled lygus bugs, whereas methoxychlor was

Table 33. Summary of means of variables considered in study of first crop red clover seed production. Ames, 1951.

Factor studied	Mean for treatment: Check	Mean for treatment: Meth-oxy-chlor	Mean for treatment: Toxa-phene, DDT	Average of all treat-ments
Insect pollinators (no./6 sq. yds.)				
Wild bees	0.00	0.00	0.03	0.01
Cantharids	0.00	0.00	0.00	0.00
Honey bees	1.0	0.6	0.2	0.6
Honey bee activity				
No. flowers visited/30 secs.	4.4	4.6	4.8	4.6
Injurious insects (no./sweep)				
Lygus sp.	3.1	2.2	0.1	1.8
Leafhoppers	0.9	0.1	0.0	0.3
Alfalfa plant bugs	0.00	0.06	0.00	0.02
Rapid plant bugs	0.00	0.03	0.00	0.01
Grasshoppers	0.28	0.00	0.00	0.09
Climatological factors				
Wind velocity (mph)	4.6	4.0	4.3	4.3
Light (10 ft. candles)	251	220	227	233
Air temperature (° F.)	72.8	71.5	71.8	72.0
Relative humidity	64.6	67.0	67.5	66.4
Vapor pressure deficit	7.6	6.6	6.5	6.9
Atmometer reading (cc./hr.)	1.7	1.7	1.7	1.7
Agronomic factors				
Stand (1-4)	2.8	2.8	2.8	2.8
Elevation (1-6)	2.5	2.2	2.2	2.3
Plant height (in.)	17	19	19	18
Plant P (%)	0.24	0.22	0.25	0.24
Plant K (%)	1.98	1.92	2.26	2.05
Soil pH	7.3	7.7	7.4	7.4
Available P (lbs./A.)	18.5	25.9	40.0	28.1
Available K (lbs./A.)	286	263	303	284
Seed yield (lbs./A.)	59	64	83	69

Table 34. Means of insect pollinators and honey bee activity by replications and treatments, first crop red clover. Ames, 1951.

Treatment	Replication	No. insect pollinators (per 6 sq. yds.)			No. flowers visited by honey bees (per 30 secs.)
		Wild bees	Can-tharids	Honey bees	
Check	I	0.00	0.00	0.0	8.4
	II	0.00	0.00	2.5	4.3
	III	0.00	0.00	0.5	3.2
	IV	0.00	0.00	1.0	1.8
Average		0.00	0.00	1.0	4.4
Methoxychlor	I	0.00	0.00	0.0	3.2
	II	0.00	0.00	1.5	5.2
	III	0.00	0.00	0.5	4.2
	IV	0.00	0.00	0.5	5.6
Average		0.00	0.00	0.6	4.6
Toxaphene, DDT	I	0.00	0.00	0.5	2.1
	II	0.00	0.00	0.0	4.5
	III	0.12	0.00	0.5	7.2
	IV	0.00	0.00	0.0	5.4
Average		0.03	0.00	0.2	4.8
Average for treatments		0.01	0.00	0.6	4.6

Table 35. Means of injurious insects by replications and treatments, first crop red clover. Ames, 1951.

Treatment	Replication	Injurious insects (number/sweep)				
		Lygus sp.	Leaf-hoppers	Alfalfa plant bugs	Rapid plant bugs	Grass-hoppers
Check	I	2.0	0.5	0.00	0.00	0.38
	II	3.5	1.0	0.00	0.00	0.12
	III	3.5	1.5	0.00	0.00	0.12
	IV	3.5	0.5	0.00	0.00	0.50
Average		3.1	0.9	0.00	0.00	0.28
Methoxychlor	I	2.5	0.0	0.00	0.00	0.00
	II	1.5	0.5	0.12	0.12	0.00
	III	1.5	0.0	0.12	0.00	0.00
	IV	3.5	0.0	0.00	0.00	0.00
Average		2.2	0.1	0.06	0.03	0.00
Toxaphene, DDT	I	0.0	0.0	0.00	0.00	0.00
	II	0.0	0.0	0.00	0.00	0.00
	III	0.5	0.0	0.00	0.00	0.00
	IV	0.0	0.0	0.00	0.00	0.00
Average		0.1	0.0	0.00	0.00	0.00
Average for treatments		1.8	0.3	0.02	0.01	0.09

Table 36. Means of climatological factors by replications and treatments, first crop red clover. Ames, 1951.

Treatment	Replication	Climatological factors: Wind velocity (mph)	Light (10 ft. candles)	Air temperature (° F.)	Relative humidity	Vapor pressure deficit	Atmometer reading (cc./hr.)
Check	I	3.8	215	71.5	65.5	7.0	1.3
	II	3.5	348	73.0	65.0	7.0	2.1
	III	6.1	94	69.0	70.0	6.0	1.3
	IV	5.0	350	77.5	58.0	10.5	2.1
Average		4.6	251	72.8	64.6	7.6	1.7
Methoxychlor	I	4.2	148	71.5	66.5	6.5	1.3
	II	3.7	290	71.5	67.5	6.5	2.1
	III	3.8	96	68.0	71.5	5.0	1.3
	IV	4.4	346	75.0	62.5	8.5	2.1
Average		4.0	220	71.5	67.0	6.6	1.7
Toxaphene, DDT	I	4.1	182	70.0	71.5	5.0	1.3
	II	2.7	324	74.0	64.5	7.5	2.1
	III	6.6	56	68.0	71.5	5.0	1.3
	IV	4.0	347	75.0	62.5	8.5	2.1
Average		4.3	227	71.8	67.5	6.5	1.7
Average for treatments		4.3	233	72.0	66.4	6.9	1.7

Table 37. Means of agronomic factors by replications and treatments, first crop red clover. Ames, 1951.

Treatment	Replication	Agronomic factors								
				Plant			Soil			
		Stand (1-4)	Elevation (1-6)	Height (in.)	P (%)	K (%)	pH	Available P (lbs./A.)	Available K (lbs./A.)	Seed yield (lbs./A.)
Check	I	3	2	19	0.16	1.44	7.5	3.0	220	42
	II	3	3	20	0.18	1.50	7.1	4.0	172	104
	III	3	3	12	0.33	2.78	7.6	44.0	400	38
	IV	2	2	17	0.28	2.19	7.1	23.0	352	52
Average		2.8	2.5	17	0.24	1.98	7.3	18.5	286	59
Methoxychlor	I	3	2	20	0.16	1.35	7.7	1.5	184	73
	II	3	2	20	0.15	1.41	7.7	1.5	216	69
	III	2	3	16	0.37	3.00	7.5	100.0	400	48
	IV	3	2	21	0.22	1.90	7.8	1.5	252	68
Average		2.8	2.2	19	0.22	1.92	7.7	25.9	263	64
Toxaphene, DDT	I	3	2	18	0.21	1.59	7.5	5.5	224	81
	II	3	2	23	0.15	1.50	7.7	3.5	188	99
	III	3	3	19	0.32	2.94	7.1	100.0	400	77
	IV	2	2	15	0.33	3.00	7.1	52.0	400	76
Average		2.8	2.2	19	0.25	2.26	7.4	40.0	303	83
Average for treatments		2.8	2.3	18	0.24	2.05	7.4	28.1	284	69

Table 38. Analysis of variance by blocks of variables studied, first crop red clover. Ames, 1951.

Source of variation	Degrees of freedom	Mean squares	F.
	Honey bee populations		
Replications	3	0.297	1.21
Treatments	2	0.252	1.02
Error	6	0.246	
	Rate of honey bee visits to flowers		
Replications	3	81.64	<1
Treatments	2	69.08	<1
Error	6	2,699.64	
	Lygus sp.		
Replications	3	0.07	<1
Treatments	2		
Insecticides *vs.* check	1	2.98	22.94**
Insecticides	1	3.83	29.43**
Error	6	0.13	
	Leafhoppers		
Replications	3	0.07	1.40
Treatments	2		
Insecticides *vs.* check	1	1.30	27.12**
Insecticides	1	0.03	<1
Error	6	0.05	
	Stand		
Replications	3	0.44	2.20
Treatments	2	0.08	<1
Error	6	0.20	
	Elevation		
Replications	3	0.67	8.04*
Treatments	2	0.08	1.02
Error	6	0.08	
	Plant height		
Replications	3	15.11	2.26
Treatments	2	5.58	<1
Error	6	6.69	

* Significant at 5 percent probability
** Significant at 1 percent probability

Table 38. (Continued)

Source of variation	Degrees of freedom	Mean squares	F.
	Plant phosphorus		
Replications	3	869.78	15.88**
Treatments	2	30.34	<1
Error	6	54.78	
	Plant potassium		
Replications	3	60,662.22	20.47**
Treatments	2	5,323.00	1.80
Error	6	2,963.89	
	Soil pH		
Replications	3	12.89	<1
Treatments	2	61.00	2.30
Error	6	28.56	
	Available phosphorus		
Replications	3	1,605,363.89	<1
Treatments	2	190,975.00	<1
Error	6	1,823,863.89	
	Available potassium		
Replications	3	120,248.89	17.78**
Treatments	2	6,448.00	<1
Error	6	6,760.89	
	Seed yield		
Replications	3	2,844.00	3.63
Treatments	2		
Insecticides *vs.* check	1	2,360.17	2.54
Insecticides	1	1,406.25	1.51
Error	6	928.50	

** Significant at 1 percent probability

comparatively ineffective. The differences in *Lygus* populations on the check and insecticide-treated plots was highly significant, as were the differences between the two insecticide treatments (Table 38).

Although the numbers of leafhoppers found on the plots were relatively low, differences in the numbers found in the checks compared to the treated plots were highly significant. In contrast to the analysis of variance, which showed significant differences between methoxychlor and the toxaphene-DDT combination spray for control of lygus bugs, there were no significant differences in leafhopper populations on areas sprayed with methoxychlor compared to those sprayed with toxaphene-DDT (Table 38). Methoxychlor was comparatively effective in controlling leafhoppers, but was not effective in controlling lygus bugs. Alfalfa plant bugs, rapid plant bugs, and grasshoppers were present only in small numbers in any of the blocks (Tables 33 and 35).

Climatological factors. Tables 33 and 36 show the average values for the climatological factors observed on first crop red clover, but these data were not analyzed statistically.

Agronomic factors. The means presented in Tables 33 and 37 and analysis of variance in Table 38 indicate that there was a uniform stand on first crop red clover. Examination of the data by analysis of variance shows a significant difference in elevation among replications (Table 38); the means disclose that Replication III was on slightly higher ground than the other two replications. Plants on the check plots appeared to be slightly shorter than those on the treated plots (Tables 33 and 37), but these differences were not statistically significant (Table 38).

There were no significant differences in plant phosphorus or potassium among the insecticide treatments, but the differences in both were highly significant among replications (Table 38). Plants from Replications III and IV consistently had higher percentages of plant phosphorus and potassium than those from Replications I and II, and these differences were highly significant.

Soil analyses showed no significant differences in soil pH or available phosphorus among replications or treatments (Table 38), but differences in available potassium were highly significant among replications.

Although there appears to be a general trend toward higher seed yields where insecticides were applied than on the check plots, these differences were not statistically significant (Table 38).

Second crop red clover

The data obtained on second crop red clover are summarized in Table 39, and more details of the means are contained in Tables 40 through 44. The analyses of variance are presented in Tables 45 and 46.

Insect pollinators. Wild bees were more plentiful on second crop red clover than on first or second crop alfalfa or first crop red clover, and counts of bees on square-yard plots show that honey bees were more plentiful than wild bees on second crop red clover (Tables 39 and 40). A few cantharids were seen.

The analysis of variance showed that differences in honey bee populations were highly significant among replications, and insecticide treatments, and for check plots compared (text continued on page 178)

Table 39. Summary of means of variables considered in study of second crop red clover seed production. Ames, 1951.

Factor studied	Mean for treatment: Check	Meth-oxy-chlor	Toxa-phene, DDT	Average all treat-ments
Insect pollinators (no./6 sq. yds.)				
Wild bees	0.19	0.12	0.09	0.13
Cantharids	0.00	0.03	0.00	0.01
Honey bees	2.3	3.4	4.8	3.5
Honey bee activity				
No. flowers visited/30 secs.	6.7	6.8	6.5	6.7
Injurious insects (no./sweep)				
Lygus sp.	7.4	6.3	0.9	4.8
Leafhoppers	3.5	1.0	1.1	1.9
Alfalfa plant bugs	0.00	0.00	0.00	0.00
Rapid plant bugs	0.22	0.00	0.00	0.07
Grasshoppers	2.35	0.00	0.00	0.78
Climatological factors				
Wind velocity (mph)	5.0	5.0	5.0	5.0
Light (10 ft. candles)	214	222	225	220
Air temperature (° F.)	79.3	79.4	79.7	79.5
Relative humidity	64.1	64.0	63.4	63.8
Vapor pressure deficit	9.3	9.4	9.7	9.4
Atmometer reading (cc./hr.)	2.2	2.2	2.2	2.2
Agronomic factors				
Stand (1-4)	2.0	2.0	2.0	2.0
Elevation (1-6)	2.2	2.2	2.2	2.2
Plant height (in.)	18	16	18	17
Plant P (%)	0.19	0.20	0.19	0.19
Plant K (%)	1.63	1.77	1.76	1.71
Soil pH	7.5	7.6	7.6	7.6
Available P (lbs./A.)	7.6	11.4	8.2	8.8
Available K (lbs./A.)	249	267	259	258
Seed yield (lbs./A.)	87	97	119	101

Table 40. Means of insect pollinators and honey bee activity by replications and treatments, second crop red clover. Ames, 1951.

Treatment	Replication	No. insect pollinators (per 6 sq. yds.)			No. flowers visited by honey bees (per 30 secs.)
		Wild bees	Can-tharids	Honey bees	
Check	I	0.00	0.00	1.6	5.9
	II	0.25	0.00	2.1	7.7
	III	0.38	0.00	2.0	7.1
	IV	0.12	0.00	3.6	6.3
Average		0.19	0.00	2.3	6.7
Methoxychlor	I	0.12	0.00	2.0	7.2
	II	0.12	0.12	3.6	6.9
	III	0.12	0.00	3.4	6.8
	IV	0.12	0.00	4.6	6.4
Average		0.12	0.03	3.4	6.8
Toxaphene, DDT	I	0.00	0.00	4.4	5.2
	II	0.12	0.00	4.1	7.2
	III	0.12	0.00	4.4	6.9
	IV	0.12	0.00	6.2	6.5
Average		0.09	0.00	4.8	6.5
Average for treatments		0.13	0.01	3.5	6.7

Table 41. Means of injurious insects by replications and treatments, second crop red clover. Ames, 1951.

Treatment	Replication	Injurious insects (number/sweep)				
		Lygus sp.	Leaf-hoppers	Alfalfa plant bugs	Rapid plant bugs	Grass-hoppers
Check	I	9.5	2.8	0.00	0.00	1.88
	II	5.9	4.1	0.00	0.38	2.15
	III	7.4	2.9	0.00	0.25	1.88
	IV	6.9	4.1	0.00	0.25	3.50
Average		7.4	3.5	0.00	0.22	2.35
Methoxychlor	I	7.1	0.6	0.00	0.00	0.00
	II	4.2	1.0	0.00	0.00	0.00
	III	4.1	1.2	0.00	0.00	0.00
	IV	9.6	1.2	0.00	0.00	0.00
Average		6.3	1.0	0.00	0.00	0.00
Toxaphene, DDT	I	1.2	1.0	0.00	0.00	0.00
	II	0.8	0.9	0.00	0.00	0.00
	III	0.8	0.9	0.00	0.00	0.00
	IV	0.8	1.5	0.00	0.00	0.00
Average		0.9	1.1	0.00	0.00	0.00
Average for treatments		4.8	1.9	0.00	0.07	0.78

Table 42. Means of climatological factors by replications and treatments, second crop red clover. Ames, 1951.

Treatment	Replication	Climatological factors: Wind velocity (mph)	Light (10 ft. candles)	Air temperature (° F.)	Relative humidity	Vapor pressure deficit	Atmometer reading (cc./hr.)
Check	I	6.8	224	79.0	69.4	8.1	2.2
	II	4.8	252	81.8	60.4	10.4	2.3
	III	3.9	192	79.4	63.6	9.4	2.5
	IV	4.6	189	77.2	62.9	9.2	1.8
Average		5.0	214	79.3	64.1	9.3	2.2
Methoxychlor	I	6.8	213	79.8	68.4	8.4	2.2
	II	4.8	233	81.1	62.1	10.2	2.3
	III	3.9	228	79.1	64.5	9.1	2.5
	IV	4.6	213	77.8	61.1	9.8	1.8
Average		5.0	222	79.4	64.0	9.4	2.2
Toxaphene, DDT	I	6.8	213	79.4	68.6	8.2	2.2
	II	4.8	271	82.1	60.5	11.2	2.3
	III	3.9	209	79.5	63.8	9.5	2.5
	IV	4.6	205	77.9	60.6	9.9	1.8
Average		5.0	225	79.7	63.4	9.7	2.2
Average for treatments		5.0	220	79.5	63.8	9.4	2.2

Table 43. Means of agronomic factors by replications and treatments, second crop red clover. Ames, 1951.

Treatment	Replication	Stand (1-4)	Elevation (1-6)	Plant: Height (in.)	Plant: P (%)	Plant: K (%)	Soil: pH	Soil: Available P (lbs./A.)	Soil: Available K (lbs./A.)	Seed yield (lbs./A.)
Check	I	2	3	16	0.26	2.06	6.9	25.0	400	90
	II	2	2	18	0.19	1.58	7.7	3.5	236	94
	III	2	2	20	0.17	1.47	7.8	1.0	184	67
	IV	2	2	20	0.14	1.41	7.7	1.0	176	96
Average		2.0	2.2	18	0.19	1.63	7.5	7.6	249	87
Methoxychlor	I	3	2	10	0.24	2.13	7.1	42.0	400	97
	II	1	3	18	0.20[a]	1.77[a]	7.8	1.0	204	106
	III	2	2	20	0.18	1.72	7.8	1.0	212	77
	IV	2	2	16	0.17	1.47	7.7	1.5	252	108
Average		2.0	2.2	16	0.20	1.77	7.6	11.4	267	97
Toxaphene, DDT	I	2	3	16	0.25	2.13	7.3	24.0	400	119
	II	2	2	20	0.16	1.56	7.7	1.0	172	146
	III	2	2	22	0.17	1.50	7.7	1.0	204	109
	IV	2	2	16	0.19	1.83	7.7	3.5	260	101
Average		2.0	2.2	18	0.19	1.76	7.6	8.2	259	119
Average for treatments		2.0	2.2	17	0.19	1.71	7.6	8.8	258	101

[a] Missing data calculated on three-plot average

Table 44. Means of nectar and pollen data and of other honey bee data by replicat
Ames, 1951.

Treatment	Replication	No. honey bees: Per 6 sq. yds.	Collected per person per minute	Exam-ined	Percent bees collected c: Pollen	Pollen only	Both pollen and nectar	Nectar only	N
Check	I	2.2	10.0	19.8	85.4	63.2	22.2	7.8	[illegible]
	II	3.0	7.8	19.4	91.0	56.4	34.8	3.0	[illegible]
	III	2.4	13.4	18.6	90.0	67.6	23.0	5.0	[illegible]
	IV	4.2	10.8	20.0	86.0	58.2	28.0	3.8	[illegible]
Average		2.9	10.5	19.4	88.1	61.4	27.0	4.9	[illegible]
Methoxychlor	I	3.0	15.0	17.0	94.0	71.4	22.6	2.6	[illegible]
	II	4.2	11.0	24.0	96.6	70.8	26.2	2.2	[illegible]
	III	2.4	16.0	16.4	79.6	64.0	16.0	11.0	[illegible]
	IV	5.2	10.6	19.6	86.6	65.6	21.2	7.4	[illegible]
Average		3.7	13.2	19.2	89.2	68.0	21.5	5.8	[illegible]
Toxaphene, DDT	I	5.6	15.8	22.2	94.4	76.0	17.8	0.0	[illegible]
	II	6.4	12.0	19.6	89.8	66.0	24.0	1.4	[illegible]
	III	3.4	13.0	17.4	77.6	60.0	18.2	19.8	[illegible]
	IV	6.6	18.6	17.2	85.8	64.6	21.4	9.2	[illegible]
Average		5.5	14.8	19.1	86.9	66.6	20.4	7.6	[illegible]
Average for treatments		4.0	12.8	19.3	88.1	65.3	23.0	6.1	[illegible]

and of other honey bee data by replications and treatments, second crop red clover.

xam-ined	Percent bees collected carrying: Pollen	Pollen only	Both pollen and nectar	Nectar only	Nectar	No load	No pollen	Average load size: Pollen	Nectar	Percent sugar in nectar
9.8	85.4	63.2	22.2	7.8	30.0	6.8	14.4	1.2	0.8	25.4
9.4	91.0	56.4	34.8	3.0	37.8	5.8	8.8	1.8	1.2	33.4
8.6	90.0	67.6	23.0	5.0	28.0	4.4	9.4	1.0	1.0	24.2
0.0	86.0	58.2	28.0	3.8	31.8	10.0	13.8	1.4	1.0	28.0
9.4	88.1	61.4	27.0	4.9	31.9	6.8	11.6	1.4	1.0	27.8
7.0	94.0	71.4	22.6	2.6	25.4	3.0	5.4	1.8	0.8	23.0
4.0	96.6	70.8	26.2	2.2	28.4	0.8	3.0	1.4	1.4	33.8
6.4	79.6	64.0	16.0	11.0	27.0	9.0	20.0	1.0	1.0	21.6
9.6	86.6	65.6	21.2	7.4	28.6	5.4	12.8	2.0	1.4	28.0
9.2	89.2	68.0	21.5	5.8	27.4	4.6	10.3	1.6	1.2	26.6
2.2	94.4	76.0	17.8	0.0	17.8	5.0	5.0	1.0	1.0	16.6
9.6	89.8	66.0	24.0	1.4	25.4	8.4	10.0	1.4	1.0	24.6
7.4	77.6	60.0	18.2	19.8	38.0	1.8	21.6	1.2	1.4	25.0
7.2	85.8	64.6	21.4	9.2	30.6	4.4	13.8	1.8	1.2	25.4
9.1	86.9	66.6	20.4	7.6	28.0	4.9	12.6	1.4	1.2	22.9
9.3	88.1	65.3	23.0	6.1	29.1	5.4	11.5	1.4	1.1	25.8

Table 45. Analyses of variance by blocks of variables studied, second crop red clover. (Data based on eight 2-day observation periods.) Ames, 1951.

Source of variation	Degrees of freedom	Mean squares	F.
	Honey bee populations		
Replications	3	164.97	15.15**
Treatments	2		
Insecticides *vs.* check	1	522.67	48.00**
Insecticides	1	242.00	22.22**
Error	6	10.89	
	Rate of honey bee visits to flowers		
Replications	3	5,130.89	2.28
Treatments	2	830.58	<1
Error	6	2,246.80	
	Lygus sp.		
Replications	3	264.11	1.60
Treatments	2		
Insecticides *vs.* check	1	2,501.04	15.14**
Insecticides	1	3,741.13	22.65**
Error	6	165.19	
	Leafhoppers		
Replications	3	245.91	3.63
Treatments	2		
Insecticides *vs.* check	1	1,661.12	24.50**
Insecticides	1	0.13	<1
Error	6	67.79	
	Stand		
Replications	3	0.22	1.00
Treatments	2	0.00	<1
Error	6	0.22	
	Elevation		
Replications	3	0.31	1.41
Treatments	2	0.00	<1
Error	6	0.22	

** Significant at 1 percent probability

Table 45. (Continued)

Source of variation	Degrees of freedom	Mean squares	F.
	Plant height		
Replications	3	23.56	6.06*
Treatments	2	8.34	2.14
Error	6	3.89	
	Plant phosphorus		
Replications	3	2,813.83	11.80**
Treatments	2	31.38	<1
Error	6	238.54	
	Plant potassium		
Replications	3	130,293.24	7.97*
Treatments	2	15,461.34	<1
Error	6	16,349.38	
	Soil pH		
Replications	3	1,926.56	22.61**
Treatments	2	44.34	<1
Error	6	85.22	
	Available phosphorus		
Replications	3	3,963,511.11	21.59**
Treatments	2	128,537.54	<1
Error	6	183,643.04	
	Available potassium		
Replications	3	1,744,981.33	26.76**
Treatments	2	20,821.34	<1
Error	6	65,194.67	
	Seed yield		
Replications	3	30,995.11	3.38
Treatments	2		
Insecticides *vs.* check	1	75,712.67	8.27*
Insecticides	1	59,858.00	6.54*
Error	6	9,157.78	

* Significant at 5 percent probability
** Significant at 1 percent probability

Table 46. Analyses of variance by blocks of honey bee, nectar, and pollen data, second crop red clover. (Data based on five 2-day observation periods.) Ames, 1951.

Source of variation	Degrees of freedom	Mean squares	F.
	Honey bee populations		
Replications	3	3.82	10.91**
Treatments	2		
Insecticides *vs*. check	1	7.26	20.74**
Insecticides	1	6.48	18.51**
Error	6	0.35	
	Rate bees were collected		
Replications	3	227.89	1.44
Treatments	2	480.58	3.04
Error	6	157.80	
	Bees examined to get nectar samples		
Replications	3	283.33	3.51
Treatments	2	3.08	<1
Error	6	80.75	
	Bees carrying pollen		
Replications	3	163.62	<1
Treatments	2	133.34	<1
Error	6	651.89	
	Bees carrying pollen only		
Replications	3	828.08	1.28
Treatments	2	1,222.34	1.89
Error	6	645.68	
	Bees carrying pollen and nectar		
Replications	3	1,218.63	8.64*
Treatments	2	1,263.25	8.96*
Error	6	140.98	
	Bees carrying nectar only		
Replications	3	5,137.56	7.25*
Treatments	2	189.00	<1
Error	6	708.28	

* Significant at 5 percent probability
** Significant at 1 percent probability

Table 46. (Continued)

Source of variation	Degrees of freedom	Mean squares	F.
	Bees carrying nectar		
Replications	3	731.84	<1
Treatments	2	611.18	<1
Error	6	791.50	
	Bees carrying no load		
Replications	3	48.22	<1
Treatments	2	139.75	<1
Error	6	292.97	
	Bees carrying no pollen		
Replications	3	1,562.33	2.30
Treatments	2	133.00	<1
Error	6	677.67	
	Pollen load size		
Replications	3	6.08	2.87
Treatments	2	1.34	<1
Error	6	2.12	
	Nectar load size		
Replications	3	1.89	1.95
Treatments	2	0.75	<1
Error	6	0.97	
	Sugar in nectar		
Replications	3	1,168.30	<1
Treatments	2	36,020.25	1.67
Error	6	21,589.26	

with treated plots (Table 45). Honey bee populations were consistently higher on plots where the toxaphene-DDT combination had been applied than on plots treated with methoxychlor (Tables 39 and 40).

Rate of honey bee visits to flowers. Honey bees visited an average of 6.7 red clover flowers in 30 seconds on second crop red clover (Tables 39 and 40). The rate of visitation was fairly uniform for all plots regardless of the insecticides applied, as evidenced by the analysis of variance (Table 45).

Injurious insects. The toxaphene-DDT combination effectively controlled lygus bugs, whereas methoxychlor was relatively ineffective; the areas treated with methoxychlor contained only slightly fewer lygus bugs than check plots (Tables 39 and 41). Differences in lygus bug populations on control areas compared to those where insecticides were applied were highly significant, as were the differences between the two insecticide treatments (Table 45).

Leafhoppers were more plentiful on second crop red clover than they were on first crop. The data in Tables 39 and 41 indicate that both the methoxychlor and toxaphene-DDT treatments greatly reduced leafhopper populations; differences in leafhopper numbers on treated plots compared to the check were significant at the 1 percent level. Few alfalfa plant bugs or rapid plant bugs were found on the second crop red clover; 2.35 grasshoppers per sweep were found on the check plots.

Climatological factors. Detailed analyses of climatological data were not made for red clover. However, the mean values for the climatological factors correspond closely with those recorded for second crop alfalfa, as might be expected since the observations on the two crops were randomized equally in time (Tables 26 and 42).

Agronomic factors. The stand of second crop red clover was quite uniform, as may be seen by the means presented in Tables 39 and 43. Comparison of the data by analysis of variance indicates that there were no significant differences in stand; the variations in elevation were slight and statistically insignificant (Table 45).

Differences in plant height were significant among replications at the 5 percent level, but were not significant among treatments (Table 45). Examination of the means (Table 43) for plant height indicates that plants were shortest on Replication I and were tallest on Replication III.

Plant and soil samples analyzed for phosphorus and potassium showed that differences in these variables were significant at the 1 percent level among replications, except plant potassium, which was significant at a probability of 5 percent (Table 45). Major source of these differences was associated with Replication I (Table 43). Mean values for plant phosphorus, plant potassium, available phosphorus, and available potassium in Replication I show that the quantities of these minerals in some tests were completely out of line with the amounts found in other replications. No definite explanation for these differences was evident.

Although a comparison of the mean values for soil pH in Tables 39 and 43 indicates only slight differences in pH among treatments, the analysis of variance showed highly significant differences in soil pH among replications. The principal source of this variation was the consistently low pH's in Replication I (Table 43).

The highest seed yields were obtained from plots treated with toxaphene-DDT (Tables 39 and 43), and analyses of variance indicated that the differences between these plots and those treated with methoxychlor were significant (Table 45). Plots treated with methoxychlor produced yields significantly higher than the check, and yields from plots treated with toxaphene-DDT were significantly higher than those from the methoxychlor-treated areas.

Honey bee, nectar, and pollen data. Honey bees were consistently more plentiful on plots sprayed with toxaphene-DDT than they were where methoxychlor was applied or on the check areas (Table 44). Analysis of variance indicated that differences in bee populations between treated and check plots were significant at the 1 percent level, and that plots where methoxychlor was applied consistently had higher bee populations than the check plots. More honey bees were found on toxaphene-DDT plots than on methoxychlor plots and these differences were highly significant (Table 46).

There were no statistical differences in the rates honey bees were collected for nectar samples, but Table 44 shows that there was a general tendency toward more rapid collection of bees on areas sprayed with insecticides than on the checks. The analysis of variance (Table 46) showed that the differences in the number of bees that had to be examined to get adequate nectar samples were not significant among replications or treatments.

An average of 88.1 percent of the bees examined and dissected for nectar analyses carried pollen (Table 44). Insecticide treatments apparently had no consistent effect on the number of bees observed gathering pollen (Table 46). The results showed that 65.3 percent of the bees examined carried pollen only, but differences in the numbers of such bees were not affected by insecticide treatments.

There was a tendency for more bees to collect pollen and nectar on check plots than on plots where insecticides had been applied, and these differences were significant at the 5 percent level (Table 46). Differences in the numbers of bees with nectar only were significant at the 5 percent level among replications (Table 46). A major portion of this difference seems to be associated with Replication IV, which consistently appeared to have more bees with no loads than the other three replications (Table 44).

Only 5.4 percent of the honey bees examined carried neither pollen nor nectar (Table 44), and there was a tendency for more bees to be found without loads on check areas than on areas sprayed with insecticides; however, these differences were not statistically significant (Table 46). An average of 29.1 percent of the bees examined carried nectar and may also have carried pollen (Table 44); the number of these bees found was fairly uniform among the various blocks (Table 46). Only 11.5 percent of the honey bees that were collected for nectar samples carried no pollen. The slight differences encountered in the number of bees carrying no pollen were not statistically significant among treatments or replications (Table 46).

The size of nectar and pollen loads collected by bees in various areas of the second crop red clover were fairly uniform; there were no significant differences associated with load size (Table 46).

The nectar collected by the bees from red clover contained an average of 25.8 percent sugar (Table 44). Although the means show a general tendency toward less sugar in the nectar collected from plants where insecticides were applied compared with check plots, these differences were not statistically significant (Table 46).

Comparison and discussion of first and second crops of alfalfa and red clover

Experiments for 1951 were designed to obtain a seasonal picture of seed production on first and second crop alfalfa. Honey bees were moved into the experimental field June 22 just as the alfalfa was starting to bloom, but only a few good days of observation were possible on first crop plots because of unusually heavy rains that persisted for several weeks; 11.70 inches in June and July were reported by Fronk (1953). As a result, only a comparatively small amount of data was obtained from first crop alfalfa and red clover; however, even though some of the data collected has limited value, the net effects of various conditions may be evaluated to some degree by the seed yields.

The principal purpose for studying red clover was to investigate its relationships to alfalfa as a competitor for honey bees. Discussion on red clover has been limited, therefore, but essentially all the data obtained from red clover are presented in the results.

Table 47 presents a comparison of certain means of variables studied on first and second crops of alfalfa and red clover. Only the means for

Table 47. Summary of means of variables considered in seed production studies on fir alfalfa and first and second crop red clover. Ames, 1951.

Factor studied	Alfalfa First crop Check	Alfalfa First crop Toxaphene, DDT	Alfalfa Second crop Check	Alfalfa Second crop Toxaphene, DDT	Red First crop Check	Red First crop Toxaphene DDT
Insect pollinators (no./6 sq. yds.)						
Wild bees	0.00	0.00	0.00	0.00	0.00	0.03
Cantharids	0.00	0.00	0.03	0.00	0.00	0.00
Honey bees	5.0	5.4	3.8	8.8	1.0	0.2
Honey bee activity						
No. flowers visited/30 secs.	9.5	9.3	9.9	9.7	4.4	4.8
No. flowers tripped by honey bees[a]	4	4	3	0		
Injurious insects (no./sweep)						
Lygus sp.	3.1	0.4	6.6	1.3	3.1	0.1
Leafhoppers	0.6	0.0	4.8	0.8	0.9	0.0
Alfalfa plant bugs	0.09	0.00	0.34	0.06	0.00	0.00
Rapid plant bugs	0.03	0.00	0.09	0.00	0.00	0.00
Grasshoppers	0.09	0.00	1.59	0.00	0.28	0.00
Climatological factors						
Wind velocity (mph)	4.4	5.0	3.9	3.9	4.6	4.3
Light (10 ft. candles)	153	292	249	250	251	227
Air temperature (° F.)	72.8	72.8	78.9	79.1	72.8	71.8
Relative humidity	65.0	66.2	65.1	65.3	64.6	67.5
Vapor pressure deficit	7.6	7.5	9.0	9.0	7.6	6.5
Atmometer reading (cc./hr.)	1.7	1.7	2.3	2.3	1.7	1.7
Agronomic factors						
Stand (1-4)	2.5	3.2	2.2	3.0	2.8	2.8
Elevation (1-6)	3.0	3.0	2.5	3.2	2.5	2.2
Plant height (in.)	23	22	22	20	17	19
Plant P (%)	0.25	0.23	0.20	0.22	0.24	0.25
Plant K (%)	1.79	1.98	1.38	1.52	1.98	2.26
Soil pH	7.1	6.9	7.3	7.3	7.3	7.4
Available P (lbs./A.)	5.0	3.6	2.2	2.6	18.5	40.0
Available K (lbs./A.)	180	205	152	160	286	303
Seed yield (lbs./A.)	26	58	11	45	59	83

[a]Totals, not averages. During the 1951 season honey bees were observed tripping a 4,783 flowers visited or 0.42 percent.

of means of variables considered in seed production studies on first and second crop and first and second crop red clover. Ames, 1951.

died	Alfalfa				Red clover			
	First crop		Second crop		First crop		Second crop	
	Check	Toxaphene, DDT	Check	Toxaphene, DDT	Check	Toxaphene, DDT	Check	Toxaphene, DDT
(no./6								
....	0.00	0.00	0.00	0.00	0.00	0.03	0.19	0.09
....	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
....	5.0	5.4	3.8	8.8	1.0	0.2	2.3	4.8
ted/30 secs.	9.5	9.3	9.9	9.7	4.4	4.8	6.7	6.5
ped by								
....	4	4	3	0				
no./sweep)								
....	3.1	0.4	6.6	1.3	3.1	0.1	7.4	0.9
....	0.6	0.0	4.8	0.8	0.9	0.0	3.5	1.1
ges	0.09	0.00	0.34	0.06	0.00	0.00	0.00	0.00
....	0.03	0.00	0.09	0.00	0.00	0.00	0.22	0.00
....	0.09	0.00	1.59	0.00	0.28	0.00	2.35	0.00
ore								
ph)	4.4	5.0	3.9	3.9	4.6	4.3	5.0	5.0
ndles)	153	292	249	250	251	227	214	225
(° F.)	72.8	72.8	78.9	79.1	72.8	71.8	79.3	79.7
y	65.0	66.2	65.1	65.3	64.6	67.5	64.1	63.4
eficit	7.6	7.5	9.0	9.0	7.6	6.5	9.3	9.7
g (cc./hr.)	1.7	1.7	2.3	2.3	1.7	1.7	2.2	2.2
....	2.5	3.2	2.2	3.0	2.8	2.8	2.0	2.0
....	3.0	3.0	2.5	3.2	2.5	2.2	2.2	2.2
.)	23	22	22	20	17	19	18	18
....	0.25	0.23	0.20	0.22	0.24	0.25	0.19	0.19
....	1.79	1.98	1.38	1.52	1.98	2.26	1.63	1.76
....	7.1	6.9	7.3	7.3	7.3	7.4	7.5	7.6
./A.)	5.0	3.6	2.2	2.6	18.5	40.0	7.6	8.2
./A.)	180	205	152	160	286	303	249	259
/A.)	26	58	11	45	59	83	87	119

es. During the 1951 season honey bees were observed tripping a total of 22 of the ted or 0.42 percent.

check plots and those for the combination toxaphene-DDT insecticide treatment are presented since they usually represent the extremes in variation.

The only wild bees observed in 1951 in the square-yard sampling areas were seen on the first and second crop of red clover. The data indicate that wild bees were not observed in first or second crop alfalfa. However, there were more wild bees present than these counts indicate, and there is little doubt that wild bees contributed to the pollination and seed yields of both alfalfa and red clover.

Cantharids, Chauliognathus pennsylvanicus, were observed occasionally but only a few were seen within the plots. Several cantharids were photographed tripping alfalfa flowers; these beetles had pollen covering the head and pronotum, but the amount of pollination they did was probably negligible.

In view of the competition between alfalfa and red clover observed in 1950 the more precise data obtained from these two crops in 1951 were especially interesting. Honey bees were more plentiful all season on alfalfa than they were on red clover, and in general there were more honey bees present on second crop alfalfa and red clover than there were on the first crops. Differences in honey bee populations on check plots and treated plots for first crop red clover were slight, but in second crop red clover there were consistently more bees in the treated areas than in the checks. Honey bee populations were fairly uniform in check and treated plots of first crop alfalfa; however, treated plots consistently had more honey bees than check plots in second crop alfalfa.

The uniform numbers of bees on first crop check plots and treated plots and the differences in check and treated plots on second crop alfalfa probably reflect to some extent the increase in injurious insects and their detrimental effect on blossoms later in the season.

A survey of the forage legumes within a 2-mile radius of the experimental field in 1951 indicated that there were many acres of crops near the field to compete for the available honey bees (Table 48). This survey did not include corn, which is reportedly a source of pollen for honey

Table 48. Approximate number of acres of forage legumes within a 2-mile radius of Agricultural Engineering field. Ames, 1951.

Crop	Number of acres
Sweetclover	6
Red clover	749
Alfalfa	365

bees under some conditions. The few times corn plants were inspected honey bees were not found gathering pollen, but several wild bees were.

General observations at Dalton field in 1950 indicated that there was more alfalfa seed produced on a first crop than on a second crop, and actual measurements of seed yields in 1951 showed there was more seed produced on first crop alfalfa than on the second. However, all yields in 1951 were low, and the statistical significance of differences between first and second crop yields were not investigated.

Counts of injurious insects in 1951 indicated that few lygus bugs and leafhoppers were present on first crop alfalfa. The smaller amount of insect injury on first crop undoubtedly contributed to differences in seed yields between first and second crops; the data also indicate more flowers were tripped on the first crop than on the second crop. Caution should be used in drawing conclusions based on such limited data as were obtained in first crop alfalfa, but it seems possible that the greater amount of tripping on first crop alfalfa and the low populations of honey bees on first crop red clover might indicate that plant competition was less and that the bees may have been less experienced in working the alfalfa during the early part of the season.

The number of injurious insects found on check plots was consistently greater than was found on treated plots. More than twice as many injurious insects were found on second crops alfalfa and red clover as were found on the first crops; increases in numbers of leafhoppers from first to second crops were approximately sevenfold. Alfalfa plant bugs, rapid plant bugs, and grasshoppers were not plentiful at any time during the season.

The data show that in all instances seed yields were increased where injurious insects were controlled by use of insecticides and, with the exception of first crop red clover, these increases were nearly the same for red clover and alfalfa. Much has been written about the great reductions in alfalfa seed that result from infestations of lygus bugs, but it was surprising to note that the effect of leafhoppers in reducing seed yields of alfalfa in these studies seemed even more drastic than the effects of lygus bugs. This result seems questionable in view of the data shown in Figure 33, which indicates that the actual effect of leafhoppers on seed yield was probably less than is predicted by the regression equation.

The rate that honey bees visited alfalfa flowers varied little on first or second crop alfalfa or on check and treated plots. However, on red clover the rate of visiting flowers appeared to be consistently lower on first crop than on the second. The differences in the rate of visitation between check and treated areas in red clover were small. The over-all average rate of flower visitation for honey bees on alfalfa was 9.6 flowers per 30 seconds compared to 6.1 flowers per 30 seconds on red clover.

Bees were not examined for pollen or nectar loads on first crop plots of alfalfa or red clover, but the data presented show that a large number of the bees examined on second crop red clover gathered pollen and at times both nectar and pollen. Differences observed in the rate bees visited red clover and alfalfa may have been due to the extra time spent collecting pollen from red clover and may indicate that more time was spent attempting to obtain nectar from red clover than from alfalfa. The data in Table 49 indicate fewer bees collected nectar from red clover than from alfalfa and that a number of bees collected both nectar and pollen from red clover at the same time.

Most of the weather data exhibited changes that might be expected in a transition from spring to summer. No apparent explanation was found for the low light readings on the check plots of first crop al-

Table 49. Summary of means for honey bee data, second crops of alfalfa and red clover. Ames, 1951.

Factor studied	Alfalfa		Red clover	
	Check	Toxaphene and DDT	Check	Toxaphene and DDT
Number of honey bees per 6 square yards	4.1	9.6	2.9	5.5
Number of bees collected per person per minute	17.6	17.5	10.5	14.8
Number of bees examined	13.4	15.3	19.4	19.1
Percentage of bees carrying				
Pollen	0.0	0.0	88.1	86.9
Pollen only	0.0	0.0	61.4	66.6
Both pollen and nectar	0.0	0.0	27.0	20.4
Nectar only	73.6	64.6	4.9	7.6
Nectar	73.6	64.6	31.9	28.0
No load	26.3	35.4	6.8	4.9
No pollen	100	100	11.6	12.6
Average load size				
Pollen	0.0	0.0	1.4	1.4
Nectar	2.0	1.8	1.0	1.2
Percent sugar in nectar	26.3	26.3	27.8	22.9

falfa, but it is doubtful that these differences had any significant effect on the other factors considered. Correlations for weather data were not calculated because of the small differences in 1951 and the results obtained in 1950, in which analysis of seasonal averages of weather data appeared to obscure short-time variations and their relationships to other factors.

There were only slight differences in the stands of check plots compared to those treated with insecticides and among areas of first crop alfalfa, second crop alfalfa, first crop red clover, and second crop red clover.

Differences in the elevation of plots of first and second crop alfalfa and first and second crop red clover were generally small, but a few differences in elevation were great enough to show trends of association with other factors. Total differences in elevation in the experimental field used in 1951 were estimated to be about 15 feet, but there were several conditions in this higher area that appeared to favor seed production. A positive relationship between elevation and seed production was demonstrated in 1950, and 1951 results also disclosed a tendency in this direction. The means in Table 27 show the blocks of Replication II in the second crop alfalfa had the highest elevation of the four replications. The means show that the most favorable conditions for seed production, as indicated by plant phosphorus, plant potassium, soil pH, and available phosphorus, were associated with Replication II. The bee populations were also highest on this replication, and although differences in bee populations were not statistically significant among replications, it appeared that one of the four treatments in Replication II (Table 24) had an extremely low bee population, which may have been responsible for this lack of significance. The low percentage of sugar in the nectar from Replication II suggests that in this instance the most favorable conditions for plants and seed production were not associated with the highest sugar content of nectar. As has been pointed out, these observations of significant differences were based on examination of the means for replications and the data were not examined by analysis of covariance. However, the apparent relationship of these conditions favorable to seed yields with the slight differences in elevation in 1951 appear to support the 1950 results which indicated that higher ground was more favorable than low ground for seed production.

The average height of alfalfa was slightly greater than that of red clover, but only small differences existed in plant height of first crop alfalfa compared to second crop and first crop red clover compared to second crop. The differences in plant height among treatments were so small they could not be correlated with seed yields.

There was a tendency toward higher percentages of phosphorus in first crop alfalfa plants compared to second and in first crop red clover plants compared to second crop, but there were not differences in the percentage of plant phosphorus associated with insecticide treatments when compared to the checks on either crop. The same trend of higher percentages of plant potassium on first crop compared to second crop was true for both alfalfa and red clover. In all instances, lower averages of plant potassium were found in check blocks than treated blocks. The correlation of plant phosphorus and seed yield was not significant, but the correlation of plant potassium approached significance.

The use of plant tissue analyses to verify results of soil tests as an indication of the possible influence of phosphorus and potassium on seed yield was not satisfactory in these studies. The reasons for the lack of relationship between these two methods of evaluating soil fertility were not investigated, but several obvious factors, such as the effects of plant diseases, insects, soil pH, soil moisture, depth of root penetration, and undoubtedly many other interrelated factors, could have obscured relationships between phosphorus and potassium in the soil to that in plants.

Variations in soil pH did not appear to be consistently associated with insecticide treatments on first or second crop alfalfa or first or second crop red clover. Soil analyses indicated a higher quantity of available phosphorus present in first crop alfalfa and first crop red clover than in the second crops. The average available phosphorus in soil where the red clover was grown was greater than the average in the soil where alfalfa was studied. The data indicate that there was a tendency for more available potassium to be present in treated plots than in checks and in first crop red clover and alfalfa than in second crops.

Most of the significant differences observed in agronomic factors on first and second crops of alfalfa and red clover were associated with replications. Although there were some large differences in available phosphorus and potassium in certain blocks, none of the other factors studied appeared to be definitely associated with these differences.

Seed yield showed a negative correlation with lygus bugs and leafhoppers and a positive correlation with honey bee populations. On alfalfa, the first crop seed yield was greater than the second, but the reverse condition was true for red clover.

Table 49 is a summary compiled to facilitate comparison of the nectar and pollen data, together with honey bee data, from second crops of alfalfa and red clover. As in Table 47, only a check and the best insecticide treatment has been included to facilitate the comparisons. Items under the heading "Number of honey bees" have previously been discussed but are included in Table 49 for convenience in observing relationships of these data to the nectar and pollen data.

A large percentage of the bees observed on red clover were carrying pollen, but none of the honey bees collected from alfalfa was carrying pollen. Some of the bees on red clover carried nectar in addition to pollen and only about 4.9 to 7.6 percent carried nectar only. In contrast, 64.6 to 73.6 percent of the bees collected from alfalfa carried only nectar. The percentage of bees without any kind of load was much higher on alfalfa than on red clover. Apparently bees on red clover were able to avoid "dry runs" by collecting both nectar and pollen from the red clover. There were only small differences in the size of nectar load bees gathered from alfalfa and red clover, and the differences in percentage of sugar in the nectar were negligible; the differences were probably less than indicated by the means, because Table 44 shows that the average sugar content of nectar from toxaphene-DDT blocks was lowered considerably by disproportionately low readings in Replication I.

Differences in the amount of sugar contained in alfalfa and red clover did not appear to explain the difference in attractiveness of the two crops. There were some evidences that the availability or quantity of nectar may have influenced the bees' choice, but this study was not designed to separate clearly the factors involved. Weather, needs of bees at the hives, differences in attractiveness of pollen and nectar, availability in terms of floral structures and relative distance from plants to the hives, time of day, and stage of plant development are among the factors which might have influenced these differences.

In summarizing the relationships of alfalfa and red clover as competitors for honey bees, it can be said that honey bees in these studies preferred alfalfa to red clover as a crop to visit, but they gathered only nectar from the alfalfa whereas a large percentage of them gathered pollen from red clover and a few also collected nectar. Honey bees were apparently effective pollinators of red clover.

The most detrimental effect of red clover as a competitor for bees in this study seemed to be that red clover was a preferred source of pollen and in this way may have reduced the necessity of gathering pollen from alfalfa.

The average size of nectar load gathered from alfalfa was slightly larger than that gathered on red clover, but such small differences probably had little significance.

Analysis of seasonal averages indicated there were only slight differences in the percentage of sugar found in nectar from alfalfa and red clover, but it is possible that short-time variations in quantity and quality of nectar were leveled out by averaging all data for the season. No differences were shown in quantity or quality of nectar by analysis of variance, and, therefore, correlations were not calculated.

SUMMARY AND CONCLUSIONS

Alfalfa seed production as it is influenced by honey bees and certain other factors was studied in and near Ames, Iowa in 1950 and 1951. In 1950 four fields were selected for study. Four colonies of honey bees per acre were moved into two of these fields, while bees were not moved into the other two. In 1951 a 28-acre field located at the Iowa State College Agricultural Engineering Farm was used for the experiments. This field was designed for studying alfalfa seed production and the influence of red clover as a competing crop for pollinators of alfalfa.

In order to determine the contribution of honey bees to seed production, counts of pollinators were made on various parts of the experimental fields. The data obtained were later analyzed to see if there was a relationship between honey bee numbers and activities and the subsequent seed yields. Observations were also made on other potential alfalfa pollinators, injurious insects, weather factors, and agronomic factors so that these influences on honey bees and on seed production might be evaluated. In 1951 a cooperative study was undertaken with Dr. O. W. Park to investigate the behavior of honey bees collecting nectar and pollen as related to seed production.

The conclusions from the 2 years' studies are as follows:

1. Attempts to establish two levels of bee populations to investigate the value of honey bees as alfalfa pollinators were not successful in 1950. Many bees which were moved into the two experimental fields foraged in neighboring fields. However, some differences in bee popula-

tions were found in both 1950 and 1951, and the experiments were so designed that these differences could be analyzed statistically and that correlations with seed yields and other factors could be calculated.

2. Seed yields were more closely correlated with honey bee populations than with any other factor studied. The regression of seed yields on honey bee populations showed that an increase of 62.2 pounds of seed per acre might have been expected for each increase of one bee per square yard under the conditions of the 1950 experiment. The regression of seed yields on bee populations in 1951 showed that under these conditions an increase of 29.9 pounds of seed per acre might have been expected with each increase of one bee per yard.

3. Counts in square-yard plots indicated that practically no wild bees were present in the alfalfa fields. However, general observations revealed the presence of some wild bees which undoubtedly aided pollination. Although a few cantharids were counted in 1951, the amount of pollination they performed was considered negligible.

4. More honey bees were counted in alfalfa than in red clover, but they much preferred red clover as a source of pollen. Seventy percent of the bees observed in alfalfa carried nectar, but none was observed collecting pollen. On red clover more than 88 percent of the bees examined carried pollen.

Pollen appeared to be the principal advantage of red clover in attracting bees, because the method of statistical analyses used showed there were only small differences in the sugar contents of nectar from red clover and alfalfa. However, it is possible that short-time variations in quantity and quality of nectar were leveled out by averaging all nectar data for the season for the analyses.

5. Honey bees were more plentiful on second crop alfalfa than they were on first crop, but they tripped a higher percentage of the flowers they visited on first crop. The first crop seed yields were greater than those from second crop.

6. The rate at which honey bees visited alfalfa flowers was most rapid in areas where bee populations were the greatest, but there was no direct relationship found between seed yield and the rate of honey bee visits.

7. Honey bees tripped an average of 0.25 percent of the second crop alfalfa flowers visited in 1950 and 0.27 percent in 1951. Competition for the bees by other plants appeared to influence the low efficiency of honey bees in pollinating alfalfa, and recent studies indicate that long-time exposure of the bees to these fields may also have contributed to their relative inefficiency in tripping. Apparently bees become more adept at working alfalfa flowers without tripping them as they gain experience.

8. Injurious insects were definitely detrimental to seed production in these investigations. The seed yields were consistently better where injurious insects were controlled than they were on unsprayed areas. The two most important kinds of injurious insects were _Lygus_ sp. and the leafhopper, _Empoasca fabae_ (Harr.). Regression analyses suggest that leafhoppers reduced seed yields more than lygus bugs, but this result seems questionable in view of the scatter of points in the regression

chart shown in Figure 33. The regression equations showed that a reduction of one lygus bug per sweep might have been expected to increase seed yields 4.8 pounds per acre, while the predicted yield increase for a reduction of one leafhopper per sweep would have been 13.6 pounds per acre.

9. Two mixtures of insecticides, toxaphene plus DDT and aldrin plus DDT, controlled lygus bugs and leafhoppers. Methoxychlor controlled leafhoppers but was relatively ineffective on lygus bugs. Honey bee numbers on check and insecticide-treated plots were fairly uniform in first crop alfalfa. However, the sprayed plots consistently had more bees than the checks in second crop alfalfa. The differences in honey bee populations on checks and sprayed plots in second crop probably reflect an increase in the detrimental effects of injurious insects to plants later in the season.

10. Based on analysis of seasonal averages, the effects of weather factors on the value of honey bees as pollinators appeared negligible. (Observations were randomized to avoid a biased influence of weather factors on bee populations or activities.) However, when the analyses of data were based on 2-day observation periods instead of on seasonal averages, the results showed that significant differences in bee populations and rate of visitation were definitely associated with short-term variations in weather. Light intensity and air temperature appeared to be positively correlated with rate of bee visits to alfalfa flowers on a seasonal basis, but rate of bee visitation was not correlated directly with seed yields.

11. Differences in plant stand were too small to show positive correlations between stands and honey bee populations or seed yields.

12. Elevation, or field topography, was associated with bee populations and seed yields; e.g., on higher areas more bees were found and more seed was produced. Definite causes of these relationships were not established, but elevation showed a near-significant, positive correlation with available phosphorus and potassium in the soil. There was little correlation between soil pH and elevation.

13. The tallest plants produced the most seed. There was a trend toward taller plants where the amounts of available phosphorus and potassium in the soil were greatest.

14. Soil pH was one of the factors most closely correlated with bee populations and seed yields. The most striking effects of pH on yields and also on honey bee populations were negative and presumably indirect. There were fewer bees and lower seed yields where plants were shortest; soil pH showed a highly significant negative correlation with plant height. Very little correlation was found between soil pH and either available phosphorus or available potassium.

15. The levels of phosphorus and potassium found in soil tests showed little or no relationship of these minerals to seed yields under the conditions of these studies. Both showed trends toward positive correlations with bee populations, but these correlations only approached significance at the 5 percent level. There was a highly significant positive correlation between available phosphorus with available potassium, and the available potassium was positively correlated with plant

height. There was little correlation between the levels of phosphorus and potassium found in alfalfa plants and those found in soil where the plants were grown. First crop plants consistently contained larger amounts of phosphorus and potassium than second crop and the plots sprayed with insecticides showed a higher average potassium content than the nonsprayed areas. Soil tests indicated that there was more available phosphorus and potassium on the first crop plots than on the second crop areas.

16. The methods of statistical analysis used failed to show any correlation between quantity of nectar or quantity of sugar in nectar to honey bee activities or to seed yields. It is possible that the range of variation in the 1951 field where nectar was studied was so small that, if such relationships existed, they were not measured. If there were differences in the amounts of nectar being produced in various parts of the field, this was not evident from the size of nectar loads carried by the bees. There was little relationship between the rate bees could be captured for the nectar analyses and the bee populations as indicated by the counts made on square-yard plots.

17. Multiple correlation studies indicated that approximately 41 percent of the variability in honey bee populations was associated with plant height, elevation, and light intensity; that 16 percent of the variation in the rate bees visited alfalfa flowers was linked to light intensity and air temperature; and that 61 percent of the variability in seed yields appeared to be lineally associated with elevation, soil pH, and honey bee populations.

18. In summary, the data suggest that alfalfa seed yields were best where: (1) the most honey bees were present; (2) competition from other plants attractive to pollinators was least; (3) injurious insects were controlled by the use of insecticides; (4) the alfalfa was located on knolls or high ground; (5) soil pH's were not too high (the range of pH's measured was 6.1 to 8.1); and (6) the quantities of available phosphorus and potassium in the soil were greatest.

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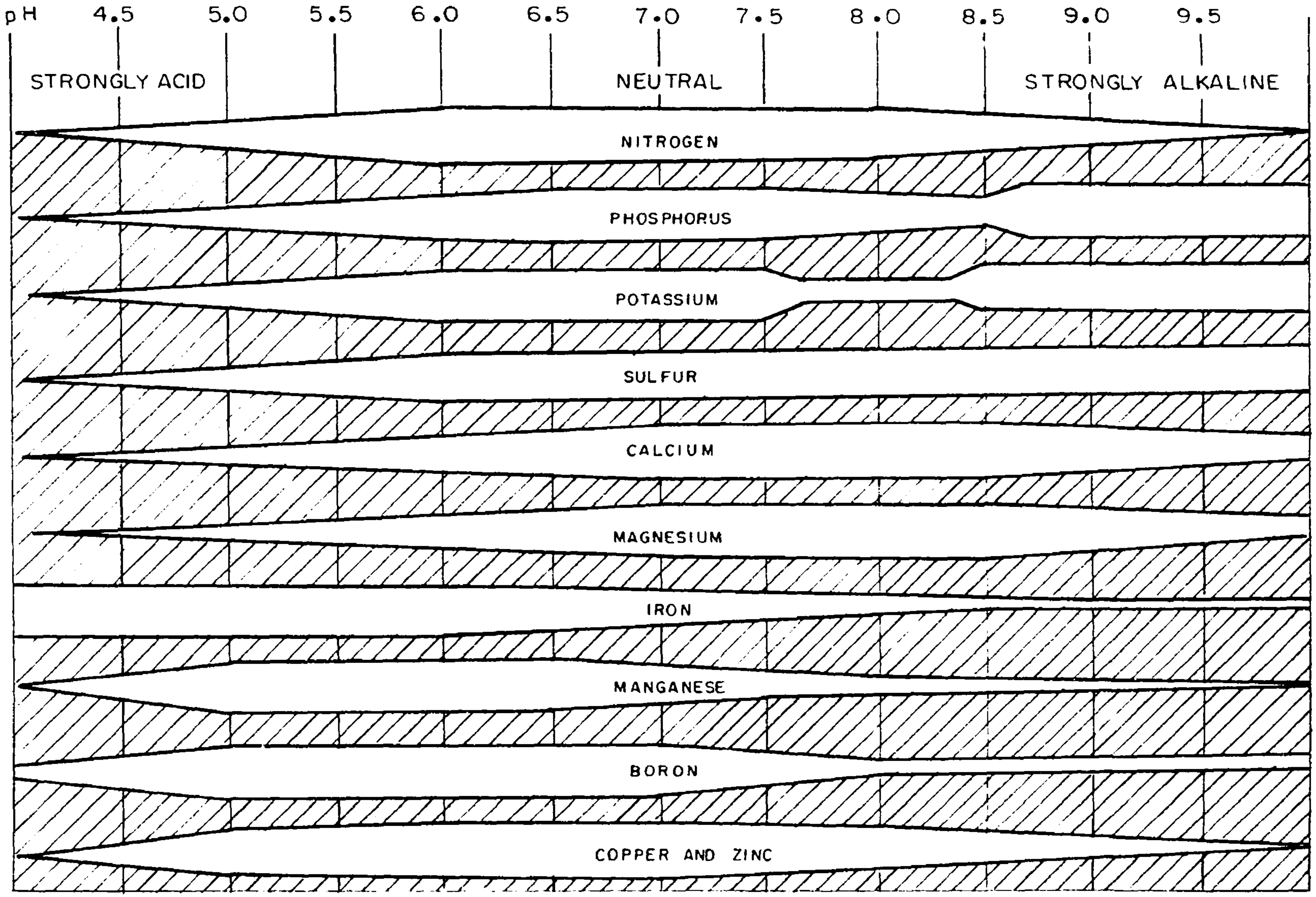
APPENDIX

Fig. 34. Influence of soil pH on availability of plant nutrients. Adapted from Truog by Thompson (1952).



Source Thompson and Truog

MAXIMUM AVAILIBILITY IS INDICATED BY THE WIDEST PART OF THE BAR.

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1 Figures showing regression are also included in this index